U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-266 179

# Economic Assessment of Waste Water Aquaculture Treatment Systems

Central State Univ, Edmond, Okla Dept of Economics

Prepared for

Robert S Kerr Environmental Research Lab, Ada, Okla

Dec 76

EPA-908/2-76-263
December 1976

PB 266 179

Environmental Protection Technology Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

# RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

## TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA-600/2-76-293 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE<br>ECONOMIC ASSESSMENT OF WASTE WATER AQUACULTURE TREATMENT SYSTEMS | | 5. REPORT DATE<br>December 1976<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Upton B. Henderson<br>Frank S. Wert | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Central State University<br>Department of Economics<br>Edmond, Oklahoma 73034 | | 10. PROGRAM ELEMENT NO.<br>1BC611<br>11. CONTRACT/GRANT NO.<br>R803623 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Robert S. Kerr Environmental Research Lab. - Ada, OK<br>Office of Research and Development<br>U. S. Environmental Protection Agency<br>Ada, Oklahoma 74820 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final - 3/75 - 7/76<br>14. SPONSORING AGENCY CODE<br>EPA/600/15 |
| 15. SUPPLEMENTARY NOTES | | |

16. ABSTRACT

This study attempted to ascertain the economic viability of aquaculture as an alternative to conventional waste water treatment systems for small municipalities in the Southwestern region of the United States. A multiple water quality objective level cost-effectiveness model was employed. A total of fifteen waste water treatment strategies, eleven with aquaculture systems and four without aquaculture, were examined. Estimates were made of the technical effectiveness and the present value of costs for all strategies. Estimates of the current value of revenues derived from sale of products produced in the aquaculture systems were made, and the impact of such revenues on total costs was analyzed.

In all cases, when aquaculture was deemed capable of achieving a given water quality objective, the aquaculture system compared to a conventional system was cost-effective. The cost differentials between aquaculture and conventional strategies were highly significant ranging from a low 3.8 percent to a high of 94 percent. While certain data limitations exist, especially in the area of water quality estimates, aquaculture systems appear to be low cost alternatives to conventional waste water treatment systems.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Aquaculture<br>Cost effectiveness<br>Wastewater treatment | Wastewater utilization<br>Fish culture | 13 B |

| | | |
|---|---|---|
| 18. DISTRIBUTION STATEMENT<br>RELEASE TO PUBLIC | 19. SECURITY CLASS *(This Report)*<br>UNCLASSIFIED | 21. NO. OF PAGES<br>120 |
| | 20. SECURITY CLASS *(This page)*<br>UNCLASSIFIED | 22. PRICE<br>PC A06 / MF A01 |

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977—757-056/5546

EPA-600/2-76-293
December 1976

# ECONOMIC ASSESSMENT OF WASTE WATER AQUACULTURE TREATMENT SYSTEMS

by

Upton B. Henderson
and
Frank S. Wert
Department of Economics
Central State University
Edmond, Oklahoma

In Consultation With

Ron Jarman
and
Settle, Dougall and Spear Engineering

Grant Number R803623

Project Officer

William R. Duffer
Wastewater Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

## DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

# ABSTRACT

This study attempted to ascertain the economic viability of aquaculture as an alternative to conventional waste water treatment systems for small municipalities in the Southwestern region of the United States. A multiple water quality objective level cost-effectiveness model was employed. A total of fifteen waste water treatment strategies, eleven with aquaculture systems and four without aquaculture, were examined. Estimates were made of the technical effectiveness and the present value of costs for all strategies. Estimates of the current value of revenues derived from sale of products produced in the aquaculture systems were made, and the impact of such revenues on total costs was analyzed.

In all cases, when aquaculture was deemed capable of achieving a given water quality objective, the aquaculture system compared to a conventional system was cost-effective. The cost differentials between aquaculture and conventional strategies were highly significant ranging from a low 3.8 percent to a high of 94 percent. While certain data limitations exist, especially in the area of water quality estimates, aquaculture systems appear to be low cost alternatives to conventional waste water treatment systems.

This report was submitted in fulfillment of Grant Number R803623-01-0 by Central State University under the sponsorship of the Environmental Protection Agency. Work was completed as of July 30, 1976.

# CONTENTS

Page

Abstract . . . . . . . . . . . . . . . . . . . . . . . . . . . iii

List of Figures . . . . . . . . . . . . . . . . . . . . . . . vi

List of Tables . . . . . . . . . . . . . . . . . . . . . . . . vii

Acknowledgments . . . . . . . . . . . . . . . . . . . . . . . viii

Conclusions . . . . . . . . . . . . . . . . . . . . . . . . . ix

Recommendations . . . . . . . . . . . . . . . . . . . . . . . xi

INTRODUCTION

- Background and Purpose . . . . . . . . . . . . . . . . . . . 1
- State of the Arts of Aquaculture . . . . . . . . . . . . . . 4
- Cost-Effectiveness as a Tool of Analysis . . . . . . . . . . 10

RESEARCH DESIGN AND METHODOLOGY

- Strategy Design and Selection . . . . . . . . . . . . . . . 14
- Cost Methodology . . . . . . . . . . . . . . . . . . . . . . 19
- Estimation of Aquaculture Parameters . . . . . . . . . . . . 24
- Aquaculture Revenue Calculations . . . . . . . . . . . . . . 38

COST DATA AND EVALUATION

- Systems Costs . . . . . . . . . . . . . . . . . . . . . . . 44
- Cost-Effective Systems . . . . . . . . . . . . . . . . . . . 58

DISCUSSION

- Work Performed . . . . . . . . . . . . . . . . . . . . . . . 75
- Problem Areas . . . . . . . . . . . . . . . . . . . . . . . 76
- Summary and Conclusions . . . . . . . . . . . . . . . . . . 79

BIBLIOGRAPHY . . . . . . . . . . . . . . . . . . . . . . . . 85

APPENDIX . . . . . . . . . . . . . . . . . . . . . . . . . . 91

Proceding page blank

## FIGURES

No. Page

1 Stage Processes for Alternative Strategies . . . . . . . . . . 16

2 Strategy Matrix . . . . . . . . . . . . . . . . . . . . . . . . 19

3 The Cost Matrix Model . . . . . . . . . . . . . . . . . . . . . 22

# TABLES

No. Page

1 Typical Polyculture System . . . . . . . . . . . . . . . . . 27

2 Estimated Fish Output From the Various Aquaculture Strategies . . . . . . . . . . . . . . . . . . . . . . . . . 30

3 Annual Stocking Rates for Monoculture . . . . . . . . . . . . 33

4 Annual Stocking Rates for Polyculture . . . . . . . . . . . . 34

5 Absolute Levels of Pollutants by Strategy and Stage . . . . 35

6 Current Fish Prices . . . . . . . . . . . . . . . . . . . . 41

7 Estimated Total Annual Revenue From Aquaculture Output . . . 43

8 Present Value of Estimated Costs by Category, Strategy and Stage . . . . . . . . . . . . . . . . . . . . . . . . 45

9 Estimated Aquaculture Operating Costs Excluding Stock . . . 51

10 Estimated Cost of Stock for Monoculture by Strategy and Species . . . . . . . . . . . . . . . . . . . . . . . . . 52

11 Estimated Cost of Stock for Polyculture by Strategy and Species . . . . . . . . . . . . . . . . . . . . . . . . . 53

12 Estimated Annual Net Revenues From Aquaculture . . . . . . . 55

13 Discounted Values for Annualized Stream of Net Revenues by Strategy for Species Yielding the Highest Net Revenues 56

14 Non-Monetary Factors Associated With Each Strategy . . . . . 59

15 Cost-Effective Systems to Achieve Alternative Objective Levels of $BOD_5$ and Suspended Solids . . . . . . . . . . . 60

16 Cost-Effective Systems to Achieve Alternative Objective Levels of Phosphorus and TKN . . . . . . . . . . . . . . . . 63

17 Classification and Analysis of Effluent Quality . . . . . . 65

18 Cumulative Percent Reduction of Pollutants, by Strategy and Stage . . . . . . . . . . . . . . . . . . . . . . . . 69

19 Rank Order of Strategies by Cumulative Costs and Stages . . 71

# ACKNOWLEDGMENTS

This research, Grant Number R803623-01-0, was made possible by a grant from the Environmental Protection Agency to Central State University, Edmond, Oklahoma. Dr. William Duffer, Wastewater Management Branch, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, served as Project Officer. Dr. Duffer provided continued support and excellent advice and guidance throughout the duration of the project.

Dr. R. LeRoy Carpenter, Commissioner of Health, Mr. Mark Coleman, Assistant Deputy Commissioner for Environmental Health Services and other members of the Oklahoma State Health Department were responsible for the pioneering effort in waste water aquaculture in the State of Oklahoma and provided invaluable information and support needed to complete this project.

The success of this project was dependent upon the support and cooperation of the Administration of Central State University. In addition, we wish to acknowledge many fish culturists who provided excellent insights essential to this project. The authors, of course, are solely accountable for any errors or omissions contained in this report.

# CONCLUSIONS

1. When the ability to reduce suspended solids and $BOD_5$ was considered, aquaculture strategies were always more cost-effective than corresponding conventional alternatives when aquaculture was capable of achieving the desired level of $BOD_5$/SS removal. The cost differential between aquaculture and conventional strategies ranged from a low of 3.8 percent to a high of 72 percent.

2. The aquaculture system was again more cost-effective in meeting nutrient removal goals when aquaculture was capable of achieving given P/TKN objectives. The cost differentials ranged from a low of 38 percent to a high of 94 percent.

3. The most cost-effective strategy to meet current secondary standards is Strategy 2, Waste Stabilization Lagoon with Aquaculture Lagoon.

4. The most cost-effective strategy to meet advanced treatment standards is a conventional system, Strategy 12, Activated Sludge--Carbon Sorption--Ammonia Removal System. This conclusion is very tentative because of the lack of adequate information on the ability of aquaculture to meet these more rigorous standards.

5. The potential revenues generated from aquaculture were not critical to the economic cost-effectiveness of aquaculture. The relative ranking of the various strategies was unaffected by the assumption of zero revenues from aquaculture.

6. Although this study raises as many questions as it answers, waste water aquaculture is definitely a low cost alternative to

conventional treatment technology and should be given serious consideration at this time as an economically feasible treatment system.

# RECOMMENDATIONS

Water quality efficiencies and aquaculture production capabilities are not well documented. It is recommended that controlled studies be initiated to ascertain the relative efficiency of varying species of fish and polyculture in terms of water quality. Variation in water quality may result, among other parameters, from different retention rates, seasonal variation in species, species composition, nutrient loading and size of fish when harvested. The effect of these variables should be documented.

It is further recommended that studies on the markets and marketability of aquaculture products be initiated. Such studies should include health considerations, alternative uses of products, size and strength of markets, and susceptibility to change. In addition, studies should ascertain the full opportunity costs of nutrients contained in waste water including the entire array of alternatives such as man-made marshes, land recycling, aquaculture lakes and lagoons and the possibility of integrated systems.

Although this study raises additional questions that need to be answered, it is nonetheless recommended that small municipalities currently give serious consideration to aquaculture wastewater treatment systems to exceed current secondary treatment standards and to reduce nutrient levels.

# INTRODUCTION

## BACKGROUND AND PURPOSE

Small communities across the nation are currently confronted with a serious economic and financial dilemma since they must meet minimum waste water treatment standards specified by the Federal Water Pollution Control Act as amended in PL 92-500 by the year 1977. Some of these communities are currently operating treatment facilities which do not meet defined secondary treatment standards. This deficiency will, in many cases, require construction and operation of more advancec treatment systems, and hence will require a substantial new commitment of community and Federal resources.

In small communities, the problem of meeting this commitment is compounded by: 1) a weak tax base, 2) eroding political support for environmental quality, 3) a lack of adequate technical knowledge to comply with environmental standards in the most economical manner, and 4) greatly inflated construction and operational costs. In addition, the sharply rising costs of conventional waste water treatment with respect to effluent quality create an additional barrier to complete and full compliance.

One technical alternative to conventional advanced waste water treatment systems is a culture of biological organisms within the system, or aquaculture. Since aquaculture systems in waste water are currently in the experimental stage of development, there is very little known about the economic feasibility of such systems serving as substitutes for the advanced conventional systems. This study will move toward filling this void and providing small communities and consulting engineers with relevant economic data upon which to base decisions.

The laws of conservation of matter obviously apply to the treatment of municipal waste water. The objective of treatment processes is to change the nature of the mass so that it can be reintroduced into the biosystem with the least possible disruption (Kneese, Ayres, et al, 1970). However, since the treatment process itself introduces new materials and energy inputs, the resulting mass increases and necessitates an ever larger mass to be disposed of. The principles of an aquaculture system are to not only facilitate disposal of the mass, but to actually transform the mass from a nuisance to a usable product--fish.

The objective of this project is to analyze and compare the costs and effectiveness of conventional waste water treatment systems with the costs and effectiveness of aquaculture waste water treatment systems for small communities with specific reference to small municipalities in the Southwest region of the United States.

To accomplish this objective the project will:

1. Determine the technical effectiveness of conventional systems with respect to effluent quality.
2. Determine the costs of conventional systems with respect to effluent quality.
3. Determine the technical effectiveness of aquaculture systems with respect to effluent quality.

4. Determine the costs of aquaculture systems with respect to the level of effluent quality.
5. Estimate the potential economically feasible by-products of aquaculture systems and associated revenues.
6. Construct an economic model to compare the cost effectiveness of the various stages of conventional treatment systems and aquaculture systems.

## STATE OF ARTS OF AQUACULTURE

The practice of utilization of human waste for production of aquaculture output is as old as the recorded history of mankind (Allen, 1970). The ancient oriental ricepaddy-carp-waterchestnut village culture is an example of an integrated waste disposal food production system.

The possibility of achieving low cost and effective water pollution control through an integrated mechanical-chemical-aquaculture system has only recently received attention in the United States (Coleman, _et_ _al_). Although it has been recognized that water pollution control embraces a wide collection of devices or actions, sanitary engineers have placed emphasis on "sewage treatment" or "waste treatment." These practices involve an "end of pipe" treatment approach which either concentrates wastes or changes the form to less harmful and environmentally damaging material. Mechanical, chemical, and energy intensive technology has eminated from this approach to "sewage treatment," and the total mass of unwanted by-products is therefore increased (Kneese, Ayres, _et_ _al_, 1970). Aquaculture as an alternative has much theoretical appeal because it can convert a large percentage of waste water contaminants to useful products. Greater utilization of natural systems such as aquaculture to achieve pollution control will tend to reduce energy and other inputs to achieve a given level of water quality. Both of these factors would, at least theoretically, reduce the cost of achieving a given level of water pollution control. Aquaculture systems, because of susceptibility to biological disruption, may more quickly bring about the need for recognization of effective "front end of pipe" water pollution control. If aquaculture treatment systems become widely used, the prevention of the introduction of toxic pesticides, heavy metals, and P.C.B.'s into municipal waste water disposal systems will become critical. The adoption of such controls may, in fact, result in better water quality at lower overall costs. Effective water pollution control using natural systems requires a more integrated approach for both "end-of-pipe" and "front-end-of-pipe" controls.

Many existing waste treatment facilities in the United States could easily convert to aquaculture with small additional costs. These additional costs might be more than offset by the market value of aquaculture products and possible gains may result from improved water quality and reduction in sludge handling and unwanted by-products of treatment.

The major obstacle to aquaculture as an acceptable and economically feasible alternative in treatment strategies is the current lack of assurance that those systems can continuously meet mandated water quality standards (Reid, 1975). In an effort to address these critical problems the Environmental Protection Agency has funded several research programs in waste water aquaculture. The bulk of this effort is directed toward determining the best species, or combination of species, of animal and plant life to 1) achieve mandated water quality parameters, and 2) to produce marketable products in order to minimize treatment costs. Research efforts need to be expanded to establish the reliability of aquaculture systems and to determine the maximum efficiency of various aquaculture alternatives.

Aquaculture alternatives appear to be attractive for the control of suspended solids in the form of algae (Carpenter, et al, 1974), as oxidation lagoons currently in operation fail to meet present secondary treatment standards for suspended solids. Control of algae by aquatic animals may be obtained in several ways. A food chain may be established in a waste water lagoon where species at the bottom of the food chain consume algae and in turn are consumed by larger predatory species which can be harvested and sold in commercial markets. Another alternative would be to utilize algae feeders directly as a source of revenue production. These organisms feed on algae either by straining the water forced through them as they swim or by remaining stationary and pumping water through their algae straining device. While the impact on water quality of such biological activity has not been firmly established, this type of system has great theoretical potential and should be thoroughly examined, including documentation of species susceptibility to biological disruption and the effects of climatic conditions on treatment processes.

A number of common species of fish of the Southwestern region of the United States may be suitable for aquaculture treatment systems. While scientific documentation is currently lacking, channel catfish, minnows, largemouth bass, buffalo, carp, and possibly gizzard shad or paddlefish appear to be feasible for waste water aquaculture systems. Marketability of these species could be confined to fish fingerlings for restocking purposes, bait fish, pet food, fertilizer or other non-human consumption uses. Prospects of production of fish for human consumption remain a possibility if health implications are resolved and public acceptance is achieved.

Several exotic aquatic organisms may be effective in achieving water quality parameters from waste water aquaculture systems. The desirable organisms must be algae feeders and be capable of achieving a rapid rate of growth. Considerable experimentation on the use of an African fish, Tilapia, has been undertaken in Oklahoma. The primary disadvantage of this exotic species is its susceptibility to biological disruption caused by low water temperatures occurring in non-tropical waters.

Another group of species with ability for algae removal is shellfish. Although less work has been done with these organisms, they may provide a more controllable situation of waste water control than free swimming species. It is easy to visualize baskets of clams being moved from lagoon to lagoon as needed to reduce algal blooms. Fish, of course, could also be caged and moved in this manner. Other animals which show promise and may be studied in the future are frogs, turtles, shrimp (fresh water variety) and prawns. All these species might be feasible alternatives but little is known about their effectiveness in achieving water quality.

The range of alternatives is not confined to aquatic animal organisms. It is definitely possible that higher aquatic plants (vascular) may be extremely effective in waste water treatment. Most aquatic plants grow rapidly and are easily harvested. Two problems concerning their use have arisen. One is the lack of a market value for the product and two is the restrictive seasonal growth in the Southwestern region of the United States.

It may be very desirable to consider alternatives to the monoculture situation in favor of combinations of species of plants and/or animals in an integrated system. A properly designed system could theoretically remove a much larger portion of waste products than could monoculture due to the various ecological niches which occur in waste water systems. This may also result in an array of output which would be less susceptible to market fluctuations than a monoculture system. Social benefits in the form of recreation may also be achieved (Hallock, et al, 1970).

Climatic variation is an extremely important factor in planning an aquaculture system. Virtually all aquatic organisms are poikilothermic in that their body temperature is the same as the surrounding environment. As temperature decreases metabolic activity decreases. This may reach a point in the winter where virtually no biological activity is occurring and at the same time waste water loads are accumulating. The result would be poor water quality and a violation of mandated standards. It may be possible to provide a set of organisms in a polyculture which would overcome this difficulty. Seasonal variation on the effectiveness of aquaculture systems cannot be overlooked. In Oklahoma's climate the normal warm water organism has a growing season of 180-210 days per year (Clemens, 1970). Standby capacity would have to be provided to correct this problem with the possibility of 160 days of standby capacity or alternative treatment strategy.

Another significant problem which must be overcome to operate an aquaculture system is that existing waste water systems are designed to treat waste water and not to culture aquatic organisms. This design characteristic may manifest itself in several areas. An important factor is the possibility of dissolved oxygen depletions in an aquaculture system. If this occurs the bulk of the aquatic organisms may be killed and the remaining organisms' activity reduced for a considerable period of time. This would necessitate re-establishing the population as well as loss of the aquaculture waste water treatment capacity.

For the aquaculture system to work the organisms produced in the system must be removed at a prescribed rate. Existing waste treatment facilities are not designed for harvesting of aquatic organisms and present an important problem in the use of these facilities. In many cases this will render aquaculture as an unwise alternative due to harvesting problems. Aquaculture systems must be designed to achieve effective harvest not only from the aspect of revenue production, but also to achieve water quality.

Many municipal systems will receive at some point in time a load of biologically toxic materials. Aquatic organisms are very susceptible to many of these materials and one exposure could eliminate a one year crop with the resulting loss of treatment. This problem must be corrected at the "front end of the pipe" or aquaculture systems will be subject to periodic disruption and possible concentration of toxic material within the organisms rendering them unfit for sale.

A final design factor which could influence the reliability of aquaculture is the depth of the facility. Most aquatic organisms are effective only close to the water surface. Large amounts of very deep water may greatly reduce the efficiency of the aquaculture system in treating the waste load. Therefore, aquaculture systems tend to require larger land units than some conventional alternatives.

The culture of most aquatic organisms is a highly technical and demanding profession. Considerable technical expertise is required for successful culture even under the best of conditions. In the small municipalities it may be beyond the capabilities of the budget and/or highly impractible to employ a fish culturist. However, this problem might be overcome by employing a fish culturist to manage several waste water aquaculture systems in a given region.

In summary, the use of aquaculture to treat waste waters is an unsettled question. It offers theoretical advantages that few other systems have and has popular support. Whether it will grow to become a major treatment technique will depend on the outcome of current research, the economic situation for municipalities, and the interest of those active in the field of waste water treatment.

## COST EFFECTIVENESS AS THE TOOL OF ANALYSIS

The private sector of the economy has long applied the principles of microeconomic theory in decision making. Public investment decisions, like their counterparts in the private sector, require capital budgeting techniques and the use of cost-benefit analyses as a major tool. The general objective of cost-benefit analysis is to measure the costs and benefits derived from social investments. The objective is to maximize economic efficiency in the allocation of limited public resources. The maximization of net benefits is achieved when the marginal cost of a specific investment is equal to the marginal benefits from the investment. Public projects are deemed economically feasible if their benefits are equal to or greater than the costs of the project.

Ideally, waste water treatment investment decisions should result from cost-benefit analysis. However, this type of analysis is not easily applied to pollution abatement programs because of the nature of the benefits derived. This type of governmental activity produces a benefit (clean water) that is not usually associated with a market. Therefore, it is difficult to quantify and attach dollar values to the benefits derived from clean water. The task is not impossible, but it requires the use of indirect-estimating techniques such as: 1) the observation and measurement of changes in the price of land, or other complementary goods, affected by the project; 2) the isolation of prices paid for close substitutes in private markets; and 3) the estimation of cost reductions made possible in other markets as a result of the project. While in some cases, indirect measures of willingness to pay (i.e. demand functions) may be derived, the major identifiable and measurable benefits derived from improved water quality are: 1) greater availability of water-based recreation; 2) improvements in commercial fishing reflected in the harvests or catch; and 3) reduction in costs of drinking water treatment for cities and towns (Davidson, _et al_, 1966).

The alternative to cost-benefit analysis is cost-effectiveness analysis. Cost evaluations are more direct and easier to obtain using cost-effectiveness analysis because only direct costs are measured. Inputs are generally obtained from private markets and hence bear readily obtainable market prices. Investment decisions and waste water treatment alternatives or strategies, may be compared given either 1) constant investment funding, or 2) a given standard of water quality.

Cost-effectiveness studies begin with the premise that some identifiable project goals are desirable and attainable and proceed to explore 1) the methods for efficient achievement or 2) costs of achieving various goal attainment levels.

Cost-effectiveness studies can be categorized into three types (Singer, 1972). The first type is a constant cost study--where an attempt is made to specify the goal to be achieved from a number of alternative programs assuming all projects are funded at the same level. The criteria for selection would be the alternative which achieves the highest goal. The second type is a least-cost study where all possible alternatives are examined to achieve a given objective or goal (e.g., 80 percent reduction in suspended solids). The criteria for selection is the alternative with the least-cost. The third type is the objective-level study which attempts to estimate the costs of achieving several alternative performance levels of the same general goal. For example, the method estimates the costs of alternative waste water treatment strategies which would achieve 1) primary standards, 2) secondary standards, and 3) tertiary or advanced standards. Varying performance standards can be evaluated in terms of the least-cost criteria, and a performance standard could be selected with some knowledge of the cost trade-offs among alternative goals. The nature of the problem and the variety of inputs indicate the use of the objective-level study method of cost-effectiveness for making investment decisions concerning waste water treatment facilities.

While there are advantages and limitations to the methodology of cost-effectiveness, the advantages are generally greater than the limitations. The advantages of cost-effectiveness over cost-benefit analysis are: 1) there is less information required; 2) it is less demanding of time and resources; and 3) Federal agencies are familiar with its practical use. The limitations of cost-effectiveness methodology are: 1) there is no indication of the economic efficiency level of performance or goals, and 2) it would not be useful in determining choices among various programs with dissimilar benefits.

# RESEARCH DESIGN AND METHODOLOGY

## STRATEGY DESIGN AND SELECTION

This study was conceived to evaluate the potential use of aquaculture as substitute water treatment processes for more conventional methods. Therefore, the primary effort was to develop treatment strategies suitable for relatively small communities which may or may not be currently meeting waste water quality standards. The objective in strategy selection was not to minimize costs, but rather to select a relatively broad spectrum of feasible treatment strategies for comparative purposes. The strategies were isolated and costs calculated using the following assumptions:

1. All systems are designed for municipalities of approximately 2,000 population having an influent flow of 200,000 gal/day.
2. Ultimate discharge is to surface waters.
3. Sludge handling is a function of the type of process employed and is included as a relevant cost.
4. In the absence of aquaculture, effluent nutrients are lost, and opportunity costs for the use of nutrients are zero.
5. Revenue functions for aquaculture output are linear, and therefore, prices are unaffected by output decisions.
6. Salvage value for physical plant and equipment is assumed to be zero, and the cost of restoring the land to salable condition is assumed to be equal to the prevailing price of land.
7. The productivity of an aquaculture lagoon or raceway is equivalent to a fully fertilized fish pond.

8. The quality of effluent from aquaculture does not vary by aquatic species.
9. Health considerations are negligible.
10. All products resulting from aquaculture are not sold for human consumption but are marketable.

Utilizing these assumptions, there was an examination of eleven strategies of municipal sewage treatment taken from a final report for the Council on Environmental Quality and the E.P.A. Office of Planning and Evaluation (E.P.A., 1974). In addition, strategies for both conventional and aquaculture systems for rural municipalities were recommended by the consulting engineer for this study. Also, the project's biologist examined other sources, made recommendations and established aquaculture design parameters.

Through working conferences, the economists, the engineer, and the biologist finally selected fifteen strategies as being appropriate, technologically feasible, waste water treatment systems to compare for the size of community under consideration. These strategies include various combinations of conventional systems, aquaculture raceways, and aquaculture fish lagoons. Figure I illustrates the "Decision Tree" upon which selection of alternatives by process, or stage, can be made.

The fifteen strategies include eleven aquaculture systems and four conventional systems. The processes are as follows; schematic illustrations are in the Appendix. Each Waste Stabilization Lagoon is a two-phase lagoon.

Strategy 1. Waste Stabilization Lagoon with an Aquaculture Raceway
Stage I--Waste Stabilization Pond
Stage II--Aquaculture Raceway

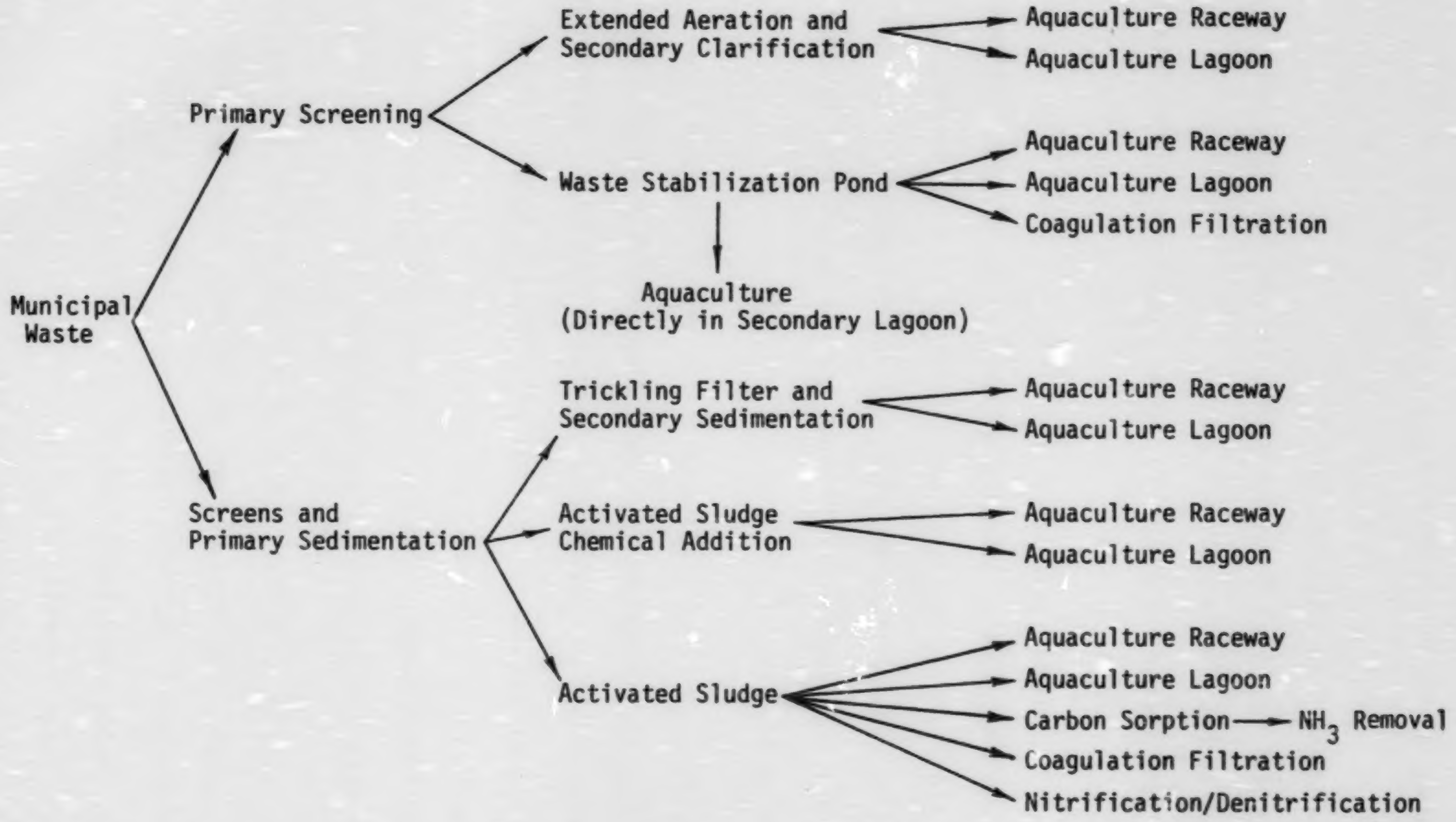

Municipal Waste
Primary Screening
Screens and Primary Sedimentation
Extended Aeration and Secondary Clarification
Waste Stabilization Pond
Aquaculture (Directly in Secondary Lagoon)
Trickling Filter and Secondary Sedimentation
Activated Sludge Chemical Addition
Activated Sludge
Aquaculture Raceway
Aquaculture Lagoon
Aquaculture Raceway
Aquaculture Lagoon
Coagulation Filtration
Aquaculture Raceway
Aquaculture Lagoon
Aquaculture Raceway
Aquaculture Lagoon
Aquaculture Raceway
Aquaculture Lagoon
Carbon Sorption
NH3 Removal
Coagulation Filtration
Nitrification/Denitrification

Figure 1. Stage Processes for Alternative Strategies

Strategy 2. Waste Stabilization Lagoon with an Aquaculture Lagoon

Stage I--Waste Stabilization Pond

Stage II--Aquaculture Lagoon

Strategy 3. Waste Stabilization Lagoon with Fish Grown Directly in the Secondary Lagoon

Stage I--Waste Stabilization Pond with Aquaculture Lagoon

Strategy 4. Trickling Filter with Aquaculture Raceway

Stage I--Primary Treatment

Stage II--Trickling Filter with Secondary Sedimentation

Stage III--Aquaculture Raceway

Strategy 5. Trickling Filter with an Aquaculture Lagoon

Stage I--Primary Treatment

Stage II--Trickling Filter with Secondary Sedimentation

Stage III--Aquaculture Lagoon

Strategy 6. Activated Sludge with an Aquaculture Raceway

Stage I--Primary Treatment

Stage II--Activated Sludge

Stage III--Aquaculture Raceway

Strategy 7. Activated Sludge with an Aquaculture Lagoon

Stage I--Primary Treatment

Stage II--Activated Sludge

Stage III--Aquaculture Lagoon

Strategy 8. Activated Sludge, Chemical Addition, with an Aquaculture Raceway

Stage I--Primary Treatment

Stage II--Activated Sludge with Chemical Addition

Stage III--Aquaculture Raceway

Strategy 9. Activated Sludge, Chemical Addition, with an Aquaculture Lagoon

Stage I--Primary Treatment

Stage II--Activated Sludge with Chemical Addition

Stage III--Aquaculture Lagoon

Strategy 10. Activated Sludge with Nitrification/Denitrification

Stage I--Primary Treatment

Stage II--Activated Sludge

Stage III--Nitrification/Denitrification

Strategy 11. Activated Sludge with Coagulation Filtration

Stage I--Primary Treatment

Stage II--Activated Sludge

Stage III--Coagulation Filtration

Strategy 12. Activated Sludge with Carbon Sorption, Ammonia Removal System

Stage I--Primary Treatment

Stage II--Activated Sludge

Stage III--Coagulation Filtration

Stage IV--Carbon Sorption

Stage V--Ammonia Removal

Strategy 13. Extended Aeration with Aquaculture Raceway

Stage I--Extended Aeration with Secondary Clarification

Stage II--Aquaculture Raceway

Strategy 14. Extended Aeration with Aquaculture Lagoon

Stage I--Extended Aeration with Secondary Clarification

Stage II--Aquaculture Lagoon

Strategy 15. Waste Stabilization Lagoon with Coagulation Filtration

Stage I--Waste Stabilization Lagoon

Stage II--Coagulation Filtration

## COST METHODOLOGY

The various feasible strategies for the treatment of municipal waste water including both conventional and aquaculture systems were broken down, by stage, into a Strategy Matrix depicted in Figure 2. The rows represent all the possible component parts, or stages, for all feasible strategies (i.e., primary treatment, activated sludge, coagulation filtration, etc.) and columns represent different strategies. An X appears for each stage used in each column; reading down a column reveals all the stages of a single strategy (e.g., strategy 3 is comprised of stages A, D, and N).

| | STRATEGY | | | | | | |
|---|---|---|---|---|---|---|---|
| STAGES | 1 | 2 | 3 | 4 | 5 | ..... | N |
| A | X | | X | X | X | ..... | X |
| B | | X | | | | | |
| C | | | | X | | | |
| D | | | X | | X | | |
| ⋮ | | | | | | | |
| N | X | X | X | X | X | ..... | X |

Figure 2. Strategy Matrix

If a cost is assigned to each stage or component, following EPA cost-effectiveness guidelines (Cost-Effectiveness Analysis, 1973), then the cost function, or model, for each strategy takes the generalized form:

$$Ci = \sum_{j=1}^{N} Xji$$

Where Ci = Present value of the total cost of the ith strategy,

Xji = The present value of the total cost of the jth component of the ith strategy.

And can be defined as:

$$Xji = Kj + \sum_{t=1}^{20} \frac{Oftj}{(1+r)^t} + \sum_{t=1}^{20} \frac{Ovtj}{(1+r)^t} - \sum_{t=1}^{20} \frac{Rtj}{(1+r)^t} - \frac{Sj}{(1+r)^t}$$

Where Kj = Capital Cost of constructing the jth component,

Oftj = Fixed annual operating and maintenance costs of the jth component in time period t, discounted for 20 years.

Ovtj = Variable annual operating and maintenance costs of the jth component in time period t, discounted for 20 years.

Rtj = Annual revenue derived from sale of output of the jth component in time period t, discounted over 20 years (assumed to be zero for all but aquaculture components).

Sj = The present salvage value of the jth component after 20 years.

r = Discount rate.

Kj capital cost includes the cost of construction, all equipment and materials, buildings, land, and all engineering charges and interest during construction.

Oftj, fixed annual operating and maintenance costs includes recurring expenditures for all labor, materials, and power and fuel used which is not a function of water flow through the system.

Ovtj, variable annual operating and maintenance costs, includes recurring expenditures that are dependent upon the level of flow through the system.

Rt is the expected annual revenue derived from the sale of the products from the aquaculture system.

Sj salvage value was assumed to be zero. The physical plant and equipment were assumed to have no salvage value and the cost of restoring the land to salable condition was assumed to be equal to the prevailing sale price of the land.

A discount rate, r, of 5-7/8 percent (EPA, 1975) was used.

The model cost matrix is presented in Figure 3. Costs for each stage of each strategy were estimated by the consulting engineer on the bases of EPA cost data (E.P.A., 1975), and engineering design proposals. All cost data were adjusted for the Southwestern region as follows:

$$\text{Total Capital Cost} = (BCC)\ \ (STP)/177.5 + (LR)\ (ULC)\ \ (100 + SIF)/100$$

Where BCC = Base Capital Cost,

STP = Change in the National Average Waste Water Treatment Plant Cost Index = (1.31)

LR = Land Requirement

ULC = Land Cost ($1,000 per acre)

SIF = Service and Interest Factor (Engineering, contingencies, and interest during construction = 27 percent).

Operation and maintenance costs were adjusted using a $4.00 per hour wage rate and the April, 1975, Wholesale Price Index of 169.7 for industrial commodities.

| STRATEGY | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Primary Treatment | $X_1$ | | | | X | X | X | X | X | X | X | X | X | | | |
| Waste Stabilization Lagoon | $X_2$ | X | X | X* | | | | | | | | | | | | X |
| Activated Sludge | $X_3$ | | | | | | X | X | | | X | X | X | | | |
| Activated Sludge, Chemical Addition | $X_4$ | | | | | | | | X | X | | | | | | |
| Extended Aeration and Secondary Clarification | $X_5$ | | | | | | | | | | | | | X | X | |
| Trickling Filter and Secondary Sedimentation | $X_6$ | | | | X | X | | | | | | | | | | |
| Coagulation Filtration | $X_7$ | | | | | | | | | | | X | X | | | X |
| Carbon Sorption | $X_8$ | | | | | | | | | | | | X | | | |
| Nitrification and Denitrification | $X_9$ | | | | | | | | | | X | | | | | |
| Ammonia Removal | $X_{10}$ | | | | | | | | | | | | X | | | |
| Aquaculture Raceway | $X_{11}$ | X | | | X | | X | | X | | | | | X | | |
| Aquaculture Lagoon | $X_{12}$ | | X | | | X | | X | | X | | | | | X | |
| | | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | $C_9$ | $C_{10}$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{15}$ |

*Fish grown directly in the waste stabilization lagoon.

Figure 3. The Cost Matrix Model

The STP cost index was adjusted for regional variation as reported in the Engineering News Record for December, 1975. The EPA complete urban sewer cost index for 25 U. S. cities, fourth quarter, 1975, was 122.8 and the index for Dallas was 86. Hence, sewer costs in Dallas were 70 percent (86/122.88) of the national average. As a result, all national capital cost data used in this study are reduced by 30 percent to adjust prices to the Dallas region. This is assumed to be representative of construction costs in the Southwest region of the United States where aquaculture appears to be feasible. In addition, all such data are expressed in April, 1975 prices.

The two major sources of cost data, A Guide to the Selection of Cost-Effective Waste Water Treatment Systems and local engineering estimates, were made compatible by adjusting for local cost differentials. EPA cost estimates adjusted to the Dallas region were available for all stages except lagoons. Local lagoon cost estimates were made by the consulting engineer and a cost index was constructed to show cost differences between local costs and the Dallas region costs. For example, trickling filter costs calculated from local price sources are $537,500 compared to $662,000 from Dallas region EPA sources. Hence EPA regional cost data are 23 percent higher ($662,000/$537,500 = 1.23) than local data and all local lagoon costs were increased by 23 percent. Appropriate adjustments have been made in all data to assure comparability on a regional basis. All cost data presented represents anticipated costs for the Dallas region.

## ESTIMATION OF AQUACULTURE PARAMETERS

A major effort was made trying to derive a direct correlation between the nutrient levels occurring in water and the amount of fish produced in that water. Several sources dealing directly with primary productivity were reviewed, but, in every case, the energy levels were either extremely tentative or based on gross assumptions. Steele (1974) described the food web of the North Sea and gave figures for yearly production. However, when referring to the resulting figure, he states, "In fact, all the values in the figure are so tentative that they must be considered as an attempt to define problems rather than to provide answers." This is the general tone of the literature on primary productivity and ecological modeling.

Allen (1970) describes the widespread use of aquaculture on a worldwide basis and gives some typical fish production figures. These figures are for species of fish which are not applicable for use in this study because of legal or marketing constraints. It should be noted that water quality is not a major consideration in other countries. The prime reason for the use of waste water aquaculture in most of the world is protein production where drastic food shortages are prevalent.

Coleman, et al (1974) in the Quail Creek Lagoon System considered aquaculture as a means to achieve water quality effluent standards. In this system of six lagoons in series, polyculture experiments conducted produced the only usable water quality data available. Schrouder (1975) described the effect of aquaculture in waste treatment ponds in Israel, but only in general terms. He summarized that aquaculture gave a lagoon system more biological "balance" or stability. The overall result was higher dissolved oxygen and pH within the lagoon.

Because of the absence of a suitable formula for computing fish production from basic measurable water quality parameters, an indirect method was utilized. Fish farming has been a growing industry in this country for approximately fifteen years. The industry is profit motivated and the major effort is directed toward maximizing fish production per unit of input. For this reason, the majority of fish farming ponds are either fertilized or fed to the maximum level possible while maintaining the water quality necessary to sustain fish life. Of prime importance is the assurance that dissolved oxygen levels are sufficient to sustain the fish while maintaining the highest level of fertilization and feeding for maximum growth.

Parallel to fish farming goals is the operation of a typical sewage lagoon. Instead of being fertilized or fed, waste is added in a predictable amount. Since the most complete oxidation of these waste products occurs in an aerobic environment it is highly desirable to maintain dissolved oxygen levels above the minimum life support level for the food web organisms in the lagoon. In lagoons this is assured by constructing the lagoon of sufficient size for oxidation at expected load levels or by providing aeration by mechanical means.

Because fish culturists are limited in the amount of fertilizer or fish feed possible to add to a pond by the size of the pond, there is a direct correlation between a fish farming pond at maximum productivity and a sewage lagoon at design capacity. Theoretically, the nutrient load on the two systems should be roughly the same and the resulting fish production should be approximately equal. For this project the assumption was made that average production in fish farms is equal to the production that could be expected from a properly operated lagoon. There is a possibility that this assumption would result in higher productivity than would be realized when water quality is the major goal of aquaculture, and hence, resulting revenues may be overstated. However, this assumption may also result in understating the potential water quality achieved from aquaculture systems.

A review of the literature was conducted of expected production by species of selected aquaculture products. The cultures selected for this project are:

| | |
|---|---|
| Carp | *Cyprinus carpio* |
| Gold Fish | *Carassius auratus* |
| Fathead Minnows | *Pimephales promelas* |
| Golden Shiner | *Notemigonus crysoleucas* |
| Channel Catfish | *Ictalurus punctatus* |
| Bigmouth Buffalo | *Ictiobus bubalas* |
| Polyculture | See Table 1 |

Meyer, *et al* (1967, 1970, 1973) documented the fish farming production in Arkansas for specific major species of fish listed above. Prather, *et al* (1954) documented bait fish production for gold fish, fathead

## TABLE 1

## TYPICAL POLYCULTURE SYSTEM

| Food Habit | Production, Max. Lbs. Per Acre | Species |
|---|---|---|
| Plankton feeder | 350 | Golden Shiner |
| Benthos feeder | 1,375 | Channel Catfish |
| Detritus feeder | 1,350 | Gold Fish |
| Specialized types-- | | |
| Zooplankton | 470 | Bigmouth Buffalo |
| Predator | 50 | Largemouth Bass |
| Insectivores | 100 | Bluegill |
| TOTAL | 3,695 | |

minnows, and golden shiners. Altman (1970) summarized national channel catfish production; Green and Mullins (1959) produced buffalo in rice-field reservoirs; and Swingle (1957) studied buffalo in the Southeastern United States. Allen (unpublished manuscript, 1976) documented production figures on a world-wide basis primarily for unspecified species of fish reared in waste water polyculture operations. Specific references of fish production are available from Germany, Java, Israel, Yugoslavia, China, Bengal, and Africa.

The data collected was converted to pounds of fish per acre and the production data by species from various literature sources were averaged. This was than assumed to be the maximum pounds of fish per surface acre that could be produced on the average in a waste water aquaculture system. To determine the rate of fish production in the project's sample system (200,000 gal/day) required an additional assumption. The engineering consultants designed a lagoon system with 3 primary treatment lagoons and 2 secondary lagoons at 3.4 acres each to treat the 200,000 gal/day waste water. Experience in lagoon treatment indicates the dissolved oxygen level in a primary lagoon is not stable and can be expected to be depleted at some time during the summer season. A secondary lagoon is much more stable and can be used for aquaculture even though oxygen depletions may occur. Therefore, assuming an aquaculture operation only in the secondary lagoons results in a total of 6.8 surface acres for fish production.

Strategy 1 fish production estimates are therefore based on maximum fish production expected in an equivalent 6.8 acres of lagoon. Strategy 2, with the same incoming water quality, could be expected to produce the same amount of fish. While Strategy 3 should have the same fish production as Strategies 1 and 2, it must be emphasized that this could only be achieved under ideal conditions. Danger to fish from oxygen depletions, heavy metal concentrations, or pesticides is much greater in a secondary lagoon such as Strategy 3, than in tertiary lagoons or raceways. In Strategies 4, 5, 6, 7, 8, 9, 13 and 14, fish production figures are based on the resulting water quality from the waste treatment stage prior to the aquaculture system. Fish production is assumed to be a linear function of the parameters of water quality directly available to the fish. Since phosphorus and nitrogen are not directly available to the fish until converted into algae or some other biological organisms, such nutrients do not affect fish production until they become limiting. Sawyer (1944) states that Phosphorus does not become limiting to algae production until 0.015 mg/l and nitrogen does not become limiting until 0.3 mg/l is reached. In all strategies these levels are exceeded and therefore the limiting factors result from the BOD-suspended solids complex. Coleman (personal conversation) states that BOD levels below 15 mg/l are limiting due to lack of a carbon source and that suspended solids would be limiting to fish production at less than 20 mg/l. Only in Strategies 8 and 9 do limitations exist and hence, the computed fish production has been reduced to 50 per cent of expected production. Expected fish productions are shown in Table 2.

The Quail Creek study involved a Polyculture system of channel catfish, golden shiners and _Tilapia nilotica_ stocked into an existing population of black bullhead, green sunfish, and mosquito fish in a six cell, serially operated lagoon system. The effluent from each cell was sampled on a weekly basis and analyzed for the following parameters: $BOD_5$; Suspended Solids; Volatile Suspended Solids, Total N; Nitrite N; Nitrate N; Ammonia N; Organic N; Total P, Fecal coliform; Turbidity; and pH. The Nitrogen forms received special emphasis because of the project goal of nutrient removal. Ammonia was reduced to less than 1.0 mg/l after the first cell which left a large portion of Total Nitrogen which is composed primarily of organic Nitrogen which is in the form of algae cells available to fish.

Nutrient removal is a very difficult technique in conventional waste treatment systems. The removal of Nitrogen and Phosphorus require very

## TABLE 2

### ESTIMATED FISH OUTPUT FROM THE VARIOUS AQUACULTURE STRATEGIES*
(Lbs. per surface acre)

| Treatment/ Strategy | Polyculture | Carp | Goldfish | Fathead Minnow | Golden Shiner | Channel Catfish | Buffalo |
|---|---|---|---|---|---|---|---|
| 1 | 3,695 | 650 | 1,355 | 306 | 383 | 1,385 | 478 |
| 2 | 3,695 | 650 | 1,355 | 306 | 383 | 1,385 | 478 |
| 3 | 3,695 | 650 | 1,355 | 306 | 383 | 1,385 | 478 |
| 4 | 1,752 | 308 | 642 | 145 | 182 | 657 | 227 |
| 5 | 1,695 | 298 | 621 | 140 | 176 | 636 | 220 |
| 6 | 1,232 | 217 | 452 | 102 | 128 | 462 | 159 |
| 7 | 1,201 | 212 | 441 | 100 | 125 | 450 | 150 |
| 8 | 547 | 96 | 201 | 45 | 57 | 205 | 71 |
| 9 | 521 | 91 | 192 | 43 | 54 | 195 | 68 |
| 13 | 1,232 | 217 | 452 | 102 | 128 | 462 | 159 |
| 14 | 1,201 | 212 | 441 | 100 | 125 | 450 | 155 |

*Anticipated fish production, pounds per surface acre (should be x 6.8 for entire unit for 200,000 gals/day flow).

sophisticated and expensive systems. Aquaculture is also ineffective at nutrient removal unless the nutrients are found in the form of algae cells or converted to some higher form of aquatic life which may be utilized by the aquaculture organisms.

Of prime interest in considering aquaculture as an alternative waste treatment technique is its ability to meet or exceed the water quality standards issued by the EPA. To determine if this will occur in the study's sample waste treatment system, the desired parameters were computed on the basis of the removal efficiencies encountered in the Quail Creek lagoon study. The actual fish production in the reference study was less than the assumed production and therefore estimates in this study represent a very conservative waste removal efficiency. Assuming a linear relationship between rate of removal of pollutants in Quail Creek and the removal from the sample system the resulting water quality was computed for the parameters $BOD_5$, Suspended Solids, Total Phosphorus, Total Nitrogen, and Total Kjeldahl Nitrogen (TKN) and is presented in Table 5. The Water Quality prior to entering the Aquaculture system was estimated by the engineering consultant and was based on the EPA report, A Guide to the Selection of Cost-Effective Waste Water Treatment Systems (EPA, 1975). The resulting water quality was computed by parameter according to proper cell effluent in the Quail Creek System.

An additional important consideration in the costs and management of an aquaculture system is the quantity of stock required each year to continue the operation. Stocking requirements were estimated on the basis of the expected outputs in Table 2. Stocking rates are presented in Table 3 for monocultures and in Table 4 for polyculture. All rates shown are adjusted for a 10 percent mortality rate.

To accurately consider the desirability of utilizing aquaculture in waste treatment systems requires some knowledge of the effect of this alternative on resulting water quality. Only one detailed study has been conducted to determine these values. Coleman, et al, (1974) measured the effect of fish production on water quality in an aquaculture system. Assumptions were made in consultations with Mr. Coleman to ascertain what levels of waste treatment would correspond with the various stages of treatment in the Quail Creek Lagoon System. From these discussions a table of resulting water quality was developed, by stage and by strategy (Table 5). The data in Table 5 assumes a linear relationship with water quality data from the Quail Creek Lagoon System.

It should be emphasized that the output and water quality data presented is highly tentative and is based on a number of extrapolation assumptions. Therefore, these data should be regarded best estimates and not as absolutes. Data were not obtained from controlled experiments. It is useful, nonetheless, for comparative purposes and for defining the potential of aquaculture systems. A number of other factors must also be considered.

Fish are poikilethermic and therefore highly affected by variation in temperatures which apply their threshold limits. Thus seasonal variation in waste water treatment effectiveness will be large. Therefore,

TABLE 3

ANNUAL STOCKING RATES FOR MONOCULTURES*
(in number of fish)

| Strategy | Carp[1]<br>3-5" Fingerling | Goldfish[2] | Fathead Minnows[2] | Golden Shiner[2] | Channel Catfish<br>2-3" Fingerling | Buffalo<br>3-5" |
|---|---|---|---|---|---|---|
| 1 | 288<br>(1958)[3] | 333<br>(2264) | 1111<br>(7555) | 1111<br>(7555) | 15374<br>(104,543) | 212<br>(1442) |
| 2 | 288<br>(1958) | 333<br>(2264) | 1111<br>(7555) | 1111<br>(7555) | 15374<br>(104,543) | 212<br>(1442) |
| 3 | 288<br>(1958) | 333<br>(2264) | 1111<br>(7555) | 1111<br>(7555) | 15374<br>(104,543) | 212<br>(1442) |
| 4 | 136<br>(924) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 7293<br>(49,592) | 101<br>(687) |
| 5 | 132<br>(899) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 7060<br>(48,008) | 98<br>(666) |
| 6 | 96<br>(653) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 4128<br>(34,870) | 71<br>(483) |
| 7 | 94<br>(639) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 4995<br>(33,966) | 69<br>(469) |
| 8 | 42<br>(286) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 2276<br>(15,477) | 31<br>(211) |
| 9 | 40<br>(272) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 2165<br>(14,722) | 30<br>(204) |
| 13 | 97<br>(660) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 5128<br>(34,870) | 71<br>(483) |
| 14 | 94<br>(639) | 222<br>(1510) | 888<br>(6038) | 888<br>(6038) | 4995<br>(33,966) | 69<br>(469) |

*Assumes a 10 percent mortality rate, hence, rates were adjusted by a factor of 1.11.

[1] Grow-out, stock fingerlings

[2] Spawning operation, stock adults

[3] First entry indicates number per acre required; number in parentheses is total number required adjusted for 6.8 acre flow equivalent.

TABLE 4

ANNUAL STOCKING RATES FOR POLYCULTURE*
(in number of fish)

| Strategy | Golden Shiner | Channel Catfish | Goldfish | Buffalo | Largemouth Bass | Bluegill |
|---|---|---|---|---|---|---|
| 1 | 11,100<br>(75,480)[1] | 15,262<br>(103,782) | 333<br>(2264) | 209<br>(1421) | 56<br>(381) | 111<br>(755) |
| 2 | 11,100<br>(75,480) | 15,262<br>(103,782) | 333<br>(2264) | 209<br>(1421) | 56<br>(381) | 111<br>(755) |
| 3 | (75,480) | 15,262<br>(103,782) | 333<br>(2264) | 209<br>(1421) | 56<br>(381) | 111<br>(755) |
| 4 | 888<br>(6038) | 7293<br>(45,592) | 222<br>(1510) | 101<br>(687) | 28<br>(190) | 56<br>(381) |
| 5 | 888<br>(6038) | 7060<br>(48,008) | 222<br>(1510) | 98<br>(666) | 28<br>(190) | 56<br>(381) |
| 6 | 888<br>(6038) | 5128<br>(34,870) | 222<br>(1510) | 71<br>(483) | 28<br>(190) | 56<br>(381) |
| 7 | 888<br>(6038) | 4995<br>(33,966) | 222<br>(1510) | 69<br>(469) | 28<br>(190) | 56<br>(381) |
| 8 | 888<br>(6038) | 2276<br>(15,477) | 222<br>(1510) | 31<br>(211) | 28<br>(190) | 56<br>(381) |
| 9 | 888<br>(6038) | 2165<br>(14,722) | 222<br>(1510) | 30<br>(204) | 28<br>(190) | 56<br>(381) |
| 13 | 888<br>(6038) | 5128<br>(34,870) | 222<br>(1510) | 71<br>(483) | 28<br>(190) | 56<br>(381) |
| 14 | 888<br>(6038) | 4995<br>(33,966) | 222<br>(1510) | 69<br>(469) | 28<br>(190) | 56<br>(381) |

*Assumes a 10 percent morality rate.

[1] First entry indicates number per acre required; number in parentheses is total number required adjusted for 6.8 acre flow equivalent.

TABLE 5

ABSOLUTE LEVELS OF POLLUTANTS, BY STRATEGY AND STAGE*

| | | No. 1 | | No. 2 | | 3 | No. 4 | | | No. 5 | | | No. 6 | | | No. 7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pollutant | Raw Influent | $X_2$ | $X_{11}$ | $X_2$ | $X_{12}$ | $X_2$ | $X_1$ | $X_6$ | $X_{11}$ | $X_1$ | $X_6$ | $X_{12}$ | $X_1$ | $X_3$ | $X_{11}$ | $X_1$ | $X_3$ | $X_{12}$ |
| $BOD_5$ mg/l | 210 | 40 | 12.5 | 40 | 12.5 | 25.8 | 140 | 30 | 15 | 140 | 30 | 9.9 | 140 | 20 | 10 | 140 | 20 | 6.6 |
| Suspended Solids mg/l | 230 | 95 | 25.4 | 95 | 25.4 | 70.9 | 110 | 34 | 19.4 | 110 | 34 | 22.8 | 110 | 25 | 14.3 | 110 | 25 | 16.8 |
| Phosphorus (as P) mg/l | 11 | 5 | 1.9 | 5 | 1.3 | 2.96 | 10 | 9 | 8.1 | 10 | 5 | 5.3 | 10 | 8 | 7.2 | 10 | 8 | 4.7 |
| TKN (as N) mg/l | 30 | 10 | | | | | 30 | 29 | | 30 | 29 | | 30 | 29 | | 30 | 29 | |
| Total N (as N) mg/l | 30 | 11 | 4.9 | 11 | 4.3 | 8.53 | 30 | 30 | 20 | 30 | 30 | 19 | 30 | 30 | 20 | 30 | 30 | 19 |

*X numbers correspond to Stage numbering in Figure 3.

## TABLE 5--Continued

| Pollutant | No. 8 | | | No. 9 | | | No. 10 | | | No. 11 | | | No. 12 | | | | | No. 13 | | No. 14 | | No. 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_4$ | $X_{11}$ | $X_1$ | $X_4$ | $X_{12}$ | $X_1$ | $X_3$ | $X_9$ | $X_1$ | $X_3$ | $X_7$ | $X_1$ | $X_3$ | $X_7$ | $X_8$ | $X_{10}$ | $X_5$ | $X_{11}$ | $X_5$ | $X_{12}$ | $X_2$ | $X_7$ |
| $BOD_5$ | 140 | 20 | 10 | 140 | 20 | 6.6 | 140 | 40 | 15 | 140 | 20 | 8 | 140 | 20 | 10 | 4 | 4 | 20 | 10 | 20 | 6.6 | 40 | 10 |
| Suspended Solids | 110 | 20 | 11.4 | 110 | 20 | 13.4 | 110 | 35 | 16 | 110 | 25 | 5 | 110 | 25 | 5 | 2 | 2 | 25 | 14.3 | 25 | 16.8 | 95 | 5 |
| Phosphorus (as P) | 10 | 2 | 1.8 | 10 | 2 | 1.2 | 10 | 9 | 9 | 10 | 8 | 0.5 | 10 | 8 | 1 | 0.8 | 0.8 | 8 | 7.2 | 8 | 4.7 | 5 | 1 |
| TKN (as N) | 30 | 29 | | 30 | 29 | | 30 | 30 | 1 | 30 | 29 | 29 | 30 | 29 | 29 | 29 | 3 | 29 | | 29 | | 10 | 10 |
| Total N (as N) | 30 | 30 | 20 | 30 | 30 | 19 | 30 | 30 | 3 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 3 | 30 | 20 | 30 | 19 | 11 | 11 |

the effectiveness of aquaculture is approximately 200 days of the year in Oklahoma.

As in the case of any biological organisms there are many factors which may disrupt the function of fish in treating waste waters. The parameter of prime importance in any waste water system is the maintenance of dissolved oxygen. Other factors include heavy metals concentration, pesticides concentration, and the presence of fish disease organisms. It must be stressed that unlike many waste water treatment systems, a disrupted aquaculture system requires a long period of time to regain effectiveness at a considerable expense for restocking. Close supervision and monitoring of an aquaculture system is required.

The use of aquaculture increases the effectiveness of lagoons and therefore requires less land than a lagoon system. However, when compared to physical-chemical techniques, it requires a larger land area.

Very little is currently known on the water quality aspect of aquaculture. It is expected that aquaculture would temper the extremes in variation which normally occur in oxidation lagoons. Overall a lagoon treatment system with aquaculture would be slightly more reliable than one without aquaculture in terms of water quality.

As demonstrated by the Santee Project (California) and a few other locations, aquaculture may be used to produce sizable recreational benefits if that is one of the goals. Americans, however, are unaccustomed to the use of waste water in this manner and may therefore underutilize the potential recreational benefits that occur.

A high degree of technical expertise as well as knowledge of fish culturist practices must be available to assure proper operation of an aquaculture system. However, this level of skill is only needed for a small portion of the total time of operation, and unskilled labor may be used the majority of the time. Marketing problems and product management impose additional managerial skills.

It is highly beneficial to demonstrate that fish are being reared in a waste water system. This would instill public confidence in the treatment system. Generally, aquaculture ponds are attractive and pleasant structures which do not distract from their natural surroundings.

Although health considerations relating to aquaculture have not been intensively studied, the tentative indications are that any additional retention time in a waste water treatment system as a result of aquaculture reduces the presence of human pathogens. The biological filtering capabilities of fish will also indirectly reduce pathogens. The concentration of heavy metals and pesticides in fish which are grown in waste waters needs study to ascertain if dangerous levels occur.

## AQUACULTURE REVENUE CALCULATIONS

Information on potential revenues were derived from reviews of literature and from direct price quotations received from fish culturists. Oklahoma Commercial Fishery Statistics for 1974 estimate that Oklahoma commercial fish growers produced 221,992 pounds of fish, consisting primarily of catfish (96 percent), with an estimated value of $224,590. These figures would indicate an average price received by commercial fish growers at $1.02 per pound in 1974 for all production (Oklahoma, 1975).

Estimates of the total poundage of bait fish sold (68 percent wholesale, 32 percent retail), consisting mostly of gizzard shad and river shiner from state waters and imported from other states, was 393,328 with a total market value of $659,314. This indicates an average price received of $1.68 per pound for bait fish in 1974 (Oklahoma, 1974).

Also, in 1974, commercial fishermen harvested 354,198 pounds of rough fish such as buffalo, carp, freshwater drum, gar, paddlefish, white bass, and flathead catfish with an estimated value of $63,784.54. These statistics indicate an average price received of $ .18 per pound. Prices varied from a low of $ .05 for gar to a high of $ .50 for flathead catfish. The retail price of channel catfish, which includes processing costs plus a regular retail markup, either whole fresh or frozen was reported at $1.29 per pound in a marketing study in Arkansas in February, 1973 (Retail, 1975).

The average wholesale price for food size catfish, live weight, in the Southern region of the United States in 1970 was $ .38 per pound (U. S. Dept. of Commerce, 1972). Adjusting this price by the Wholesale Price Index for Farm Products for 1975 prices yields an average price of $ .63 per pound.

The price for catfish fingerlings in 1970 was reported ranging from $ .03 to $ .08 each. Assuming catfish of 6" to 8" in length weigh 0.1 pound each in live weight, these figures convert to a price of

$ .30 to $ .80 per pound. In terms of 1975 prices adjusted by the Wholesale Price Index for Farm Products, these figures convert to from $ .47 to $1.26 per pound for small catfish. Prices paid to commercial fish growers in the Southern region of the U.S. in 1970 were reported in the same study to range from $ .35 to $ .40 for food size live weight catfish. In terms of 1975 prices, these figures adjust to $ .55 to $ .63 per pound. Processing was reported to add 50 percent to the value of the product.

Commercial fish prices in Arkansas adjusted by Wholesale Price Index for Farm Products, are presented in Table 6. These prices tend generally to support the price quotes received in a separate study from 18 licensed fish growers in Oklahoma, 4 in Texas and 13 in Arkansas. The average price quotations from these sources are as follows for live bait fish:

| | |
|---|---|
| Golden Shiner (FOB) | $1.70/lb. |
| Fathead Minnows (FOB) | 1.65/lb. |
| Sunfish (FOB) | .85/lb. |
| Channel Catfish (FOB), food size, live weight | .82/lb. |
| Catfish (FOB), live weight 6" to 8" | 2.50/lb. |

Very few price quotations were received for buffalo, carp, largemouth bass, and bluegill.

Price quotes received from commercial fishermen in Oklahoma, Arkansas, and Texas, in average price live weight (FOB) were used in this study. This data is presented in Table 6. It should be noted that these prices will vary from region to region and by seasonal supply fluctuations.

## TABLE 6

## CURRENT FISH PRICES
($ per lb.)

| Species | Quoted Prices | Arkansas[1] | Oklahoma | Price Used in Study |
|---|---|---|---|---|
| Goldfish | $1.75 | | | $1.75 |
| Golden Shiners | 1.70 | $2.20 | $1.68 | 1.70 |
| Fathead Minnow | 1.65 | 1.32 | 1.68 | 1.65 |
| Catfish | | | | |
| 6"-8" | 2.50 | -- | -- | 2.50 |
| Food Size | .82 | .79 | 1.02 | |
| All Sizes | | 1.04 | | |
| Carp | -- | .88 | -- | .17 |
| Buffalo | .40 | .35 | -- | .20 |
| Bass, Sunfish | | | | |
| Fingerling | | 1.76 | | |
| Food Size | | .88 | | |
| Polyculture[2] | | | | 1.02 |

[1] 1966 quotations adjusted to 1975 prices. Fred P. Meyer, D. Leroy Gray, William P. Mathis, J. Mayo Martin, and B. R. Wells, Production and Returns from the Commercial Production of Fish in Arkansas during 1966.

[2] Average price received in Oklahoma for all commercially grown fish in 1974.

Live bait prices are particularly susceptible to such forces and are therefore exceptionally unstable. Good marketing information and fish brokerage services are currently unavailable.

Estimates of potential revenues from waste water aquaculture systems were derived using the average quote price column four of Table 6. Estimated annual production figures (Table 2) supplied by the project's biologist were multiplied by price estimates to derive the estimated revenues from an aquaculture system. Table 7 summarizes the potential revenues from waste water aquaculture systems.

Data in Table 7 indicates that fish from a polyculture system, primarily sold for bait purposes, is the best revenue producer. Channel catfish production is second best alternative insofar as gross revenues are concerned in Strategies 1, 2 or 3. Regional conditions, changing prices, and other market conditions, of course, could change the gross revenue estimates. Much more marketing research is needed to determine potential future market prices, alternative products and innovative uses of nutrients from waste water treatment systems.

## TABLE 7

## ESTIMATED TOTAL ANNUAL REVENUE FROM AQUACULTURE OUTPUT ($)

| Strategy | Carp[1] | Buffalo[2] | Channel Catfish[3] | Goldfish[4] | Fathead Minnows[5] | Golden Shiner[6] | Polyculture[7] |
|---|---|---|---|---|---|---|---|
| 1 | $ 751 | $ 650 | $ 23,545 | $ 16,125 | $ 3,434 | $ 4,427 | $ 25,629 |
| 2 | 751 | 650 | 23,545 | 16,125 | 3,434 | 4,427 | 25,629 |
| 3 | 751 | 650 | 23,545 | 16,125 | 3,434 | 4,427 | 25,629 |
| 4 | 356 | 309 | 11,170 | 7,641 | 1,627 | 2,105 | 12,152 |
| 5 | 344 | 299 | 10,813 | 7,390 | 1.571 | 1,389 | 11,757 |
| 6 | 251 | 216 | 7,855 | 5,380 | 1,145 | 1,479 | 8,547 |
| 7 | 245 | 204 | 7,650 | 5,248 | 1,122 | 1,445 | 8,330 |
| 8 | 111 | 97 | 3,485 | 2,392 | 505 | 660 | 3,795 |
| 9 | 105 | 92 | 3,315 | 2,286 | 482 | 624 | 3,614 |
| 13 | 251 | 216 | 7,855 | 5,380 | 1,145 | 1,479 | 8,546 |
| 14 | 245 | 211 | 7,650 | 5,248 | 1,122 | 1,445 | 8,330 |

[1] $ .17/lb.
[2] .20/lb.
[3] 2.50/lb.
[4] 1.75/lb.
[5] 1.65/lb.
[6] 1.16/lb.
[7] 1.02/lb.

# COST DATA AND EVALUATION

## SYSTEMS COSTS

The construction, operation and maintenance costs of the fifteen strategies were compiled using the methodology discussed in the previous section of this report and are presented in Table 8. Costs are summarized in terms of current costs and discounted annualized streams by cost category, by stage and by strategy. The total costs are the present value of all costs associated with treating 200,000 gal/day of water for a twenty-year period. The discount factor employed was 5-7/8 percent. The costs presented here are not intended to represent exact projections for specific processes and areas, but rather are intended to serve as a comparative analysis so that generalized statements regarding costs and effectiveness of alternative treatment systems can be made.

Where possible, annual operating costs (O) were further categorized into operating fixed costs (costs independent of flow) and operating variable costs (costs dependent upon flow). The (R) cost category contained in all of the aquaculture systems is negative and represents the revenues received from the sale of aquaculture output minus the cost of stock to produce that output. A negative (R) is thus a cash flow back to the operating institution and serves to reduce the total costs of water treatment. The (R's) contained in Table 8 are the highest projections estimated (production and sale of polyculture output) and must be interpreted as the best possible revenue position under the assumptions of this analysis.

## TABLE 8

## PRESENT VALUE OF ESTIMATED COSTS BY CATEGORY, STRATEGY, AND STAGE*
($)

| | | Current Costs | Discounted** Annualized Stream | |
|---|---|---|---|---|
| Strategy 1. Waste Stabilization Lagoon with Aquaculture Raceway | | | | |
| Stage I ($X_2$)--Waste Stabilization Pond | K = | $202,000 | $202,000 | |
| | O = | 8,500 | 98,515 | $300,515 |
| Stage II ($X_{11}$) -Aquaculture Raceway | K = | 111,930 | 111,930 | |
| | O = | 5,877 | 68,114 | |
| | R = | -20,749 | -240,481 | -60,437 |
| | | | TOTAL | $240,078 |
| Strategy 2. Waste Stabilization Lagoon with Aquaculture Lagoon | | | | |
| Stage I ($X_2$)--Waste Stabilization Pond | K = | 202,000 | 202,000 | |
| | O = | 8,500 | 98,515 | 300,515 |
| Stage II ($X_{12}$)--Aquaculture Lagoon | K = | 42,500 | 42,500 | |
| | O = | 7,373 | 85,453 | |
| | R = | 20,749 | -240,481 | -112,528 |
| | | | TOTAL | $187,987 |
| Strategy 3. Waste Stabilization Lagoon with Fish | | | | |
| Stage I ($X_2$)--Waste Stabilization Pond | K = | 202,000 | 202,000 | |
| | O = | 8,500 | 98,515 | 300,515 |
| --Aquaculture Lagoon in $X_2$ | K = | None | | |
| | O = | 7,373 | 85,453 | |
| | R = | 20,749 | -240,481 | -155,028 |
| | | | TOTAL | $145,487 |

*K = Capital Costs, O = Annual Operating (v = variable, f = fixed), and R = net revenues from a polyculture aquaculture system.

**Discount base of 5-7/8 percent

TABLE 8--Continued

| | | Current Costs | Discounted Annualized Stream | |
|---|---|---|---|---|
| **Strategy 4.** Trickling Filter with Aquaculture Raceway | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | $293,800 | $293,800 | |
| | Of = | 7,630 | 88,431 | |
| | v = | 1,937 | 22,452 | $404,683 |
| Stage II ($X_6$)--Trickling Filter & Secondary Sedimentation | K = | 398,200 | 398,200 | |
| | Of = | 6,629 | 72,664 | |
| | v = | 6,202 | 71,866 | 542,730 |
| Stage III ($X_{11}$)--Aquaculture Raceway | K = | 111,930 | 111,930 | |
| | O = | 5,877 | 68,114 | |
| | R = | -10,616 | -123,039 | 57,005 |
| | | | TOTAL | $1,004,418 |
| **Strategy 5.** Trickling Filter with Aquaculture Lagoon | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 293,800 | 293,800 | |
| | Of = | 7,630 | 88,431 | |
| | v = | 1,937 | 22,452 | 404,683 |
| Stage II ($X_6$)--Trickling Filter & Secondary Sedimentation | K = | 398,200 | 398,200 | |
| | Of = | 6,629 | 72,664 | |
| | v = | 6,202 | 71,866 | 542,730 |
| Stage III ($X_{12}$)--Aquaculture Lagoon | K = | 42,500 | 42,500 | |
| | O = | 7,373 | 85,453 | |
| | R = | 10,150 | -117,639 | 10,314 |
| | | | TOTAL | $957,727 |
| **Strategy 6.** Activated Sludge with Aquaculture Raceway | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 274,600 | 274,600 | |
| | Of = | 7,630 | 88,431 | |
| | v = | 1,729 | 20,040 | 383,071 |
| Stage II ($X_3$)--Activated Sludge | K = | 568,800 | 568,800 | |
| | Of = | 11,211 | 129,933 | |
| | v = | 4,931 | 57,156 | 755,889 |
| Stage III ($X_{11}$)--Aquaculture Raceway | K = | 111,930 | 111,930 | |
| | O = | 5,877 | 68,114 | |
| | R = | 7,342 | -85,094 | 94,950 |
| | | | TOTAL | $1,233,910 |

TABLE 8--Continued

| | | Current Costs | Discounted Annualized Stream | |
|---|---|---|---|---|
| Strategy 7. Activated Sludge with Aquaculture Lagoon | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | $274,600 | $274,600 | |
| | Of = | 7,630 | 88,431 | |
| | v = | 1,729 | 20,040 | $383,071 |
| Stage II ($X_3$)--Activated Sludge | K = | 568,800 | 568,800 | |
| | Of = | 11,211 | 129,933 | |
| | v = | 4,931 | 57,156 | 755,889 |
| Stage III (X12)--Aquaculture Lagoon | K = | 42,500 | 42,500 | |
| | O = | 7,373 | 85,453 | |
| | R = | -7,151 | -82,880 | 45,073 |
| | | | TOTAL | $1,184,033 |
| Strategy 8. Activated Sludge--Chemical Addition with Aquaculture Raceway | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 249,560 | 249,560 | |
| | Of = | 6,354 | 73,647 | |
| | v = | 1,504 | 17,426 | 340,633 |
| Stage II ($X_4$)--Activated Sludge with Chemical Addition | K = | 629,440 | 629,440 | |
| | Of = | 11,925 | 138,212 | |
| | v = | 5,174 | 59,971 | 827,623 |
| Stage III ($X_{11}$)--Aquaculture Raceway | K = | 111,930 | 111,930 | |
| | O = | 5,877 | 68,114 | |
| | R = | -3,185 | -36,914 | 143,130 |
| | | | TOTAL | $1,311,386 |
| Strategy 9. Activated Sludge--Chemical Addition with Aquaculture Lagoon | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 249,560 | 249,560 | |
| | Of = | 6,354 | 73,647 | |
| | v = | 1,504 | 17,426 | 340,633 |
| Stage II ($X_4$)--Activated Sludge with Chemical Addition | K = | 629,440 | 629,440 | |
| | Of = | 11,925 | 138,212 | |
| | v = | 5,174 | 59,971 | 827,623 |
| Stage III ($X_{12}$)--Aquaculture Lagoon | K = | 42,500 | 42,500 | |
| | O = | 7,373 | 85,453 | |
| | R = | 3,004 | -34,816 | 93,137 |
| | | | TOTAL | $1,261,393 |

TABLE 8--Continued

| | | Current Costs | Discounted Annualized Stream | |
|---|---|---|---|---|
| **Strategy 10.** Activated Sludge with Denitrification System | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | $281,000 | $281,000 | |
| | Of = | 7,222 | 83,700 | |
| | v = | 1,798 | 20,844 | $385,544 |
| Stage II ($X_3$)--Activated Sludge | K = | 471,000 | 471,000 | |
| | Of = | 9,561 | 110,809 | |
| | v = | 4,900 | 56,796 | 638,605 |
| Stage III ($X_9$)--Nitrification & Denitrification | K = | 515,000 | 515,000 | |
| | Of= | 15,367 | 178,104 | |
| | v = | 3,629 | 42,060 | 735,164 |
| | | | TOTAL | $1,759,313 |
| **Strategy 11.** Activated Sludge with Coagulation Filtration System | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 274,600 | 274,600 | |
| | Of = | 7,018 | 81,334 | |
| | v = | 1,729 | 20,040 | 375,974 |
| Stage II ($X_3$)--Activated Sludge | K = | 652,800 | 652,800 | |
| | Of = | 16,211 | 187,882 | |
| | v = | 6,631 | 76,859 | 917,541 |
| Stage III ($X_7$)--Coagulation Filtration | K = | 753,000 | 753,000 | |
| | Of = | 19,710 | 228,439 | |
| | v = | 10,950 | 126,911 | 1,108,350 |
| | | | TOTAL | $2,401,865 |
| **Strategy 12.** Activated Sludge with Carbon Sorption, Ammonia Removal System | | | | |
| Stage I ($X_1$)--Primary Treatment | K = | 274,600 | 274,600 | |
| | Of = | 7,018 | 81,334 | |
| | v = | 1,729 | 20,040 | 375,974 |
| Stage II ($X_3$)--Activated Sludge | K = | 652,800 | 652,800 | |
| | Of = | 16,211 | 187,882 | |
| | v = | 6,631 | 76,859 | 917,541 |
| Stage III ($X_7$)--Coagulation Filtration | K = | 677,000 | 677,000 | |
| | Of = | 19,710 | 228,439 | |
| | v = | 10,950 | 126,911 | 1,032,350 |

TABLE 8--Continued

| | Current Costs | Discounted Annualized Stream | |
|---|---|---|---|
| Strategy 12--Continued | | | |
| Stage IV ($X_8$)--Carbon Sorption | K = $753,000 | $753,000 | |
| | O = 730 | 8,461 | $761,461 |
| Stage V ($X_{10}$)--Ammonia Removal | K = 25,000 | 25,000 | |
| | Of = 13,870 | 160,753 | |
| | v = 3,650 | 42,304 | 228,057 |
| | | TOTAL | $3,315,383 |
| Strategy 13. Extended Aeration with Aquaculture Raceway | | | |
| Stage I ($X_5$)--Extended Aeration | K = 516,000 | 516,000 | |
| and Secondary | Of = 9,417 | 109,143 | |
| Clarification | v = 4,898 | 56,764 | 681,907 |
| Stage II ($X_{11}$)--Aquaculture | K = 111,930 | 111,930 | |
| Raceway | O = 5,877 | 68,114 | |
| | R = 7,347 | -85,082 | 94,962 |
| | | TOTAL | $776,869 |
| Strategy 14. Extended Aeration with Aquaculture Lagoon | | | |
| Stage I ($X_5$)--Extended Aeration | K = 516,000 | 516,000 | |
| and Secondary | Of = 9,417 | 109,143 | |
| Clarification | v = 4,898 | 56,764 | 681,907 |
| Stage II ($X_{12}$)--Aquaculture | K = 42,500 | 42,500 | |
| Lagoon | O = 7,373 | 85,453 | |
| | R = -7,153 | -82,903 | 45,050 |
| | | TOTAL | $726,957 |
| Strategy 15. Waste Stabilization Lagoon with Coagulation Filtration | | | |
| Stage I ($X_2$)--Waste Stabilization Pond | K = 202,000 | 202,000 | |
| | O = 8,600 | 99,674 | 301,674 |
| Stage II ($X_7$)--Coagulation | K = 753,000 | 753,000 | |
| Filtration | Of = 20,284 | 235,093 | |
| | v = 12,010 | 139,194 | 1,127,287 |
| | | TOTAL | $1,428,961 |

While the costs of conventional stages and strategies are largely self-explanatory, the derivation of aquaculture costs requires some explanation. Three types of aquaculture physical plants were selected and costs allocated accordingly. The first is a three cell aquaculture raceway ($X_{11}$) designed primarily to facilitate fish handling, the second ($X_{12}$) is a single fish lagoon system to be built as an additional stage of a conventional system. Strategy 3 requires no new construction but is simply a grow-out or fish spawning operation directly in a secondary oxidation wastewater lagoon. All three systems have different costs because of varying physical and operational characteristics. In all three the resulting net revenues are species dependent. That is, they reflect varying prices anticipated from the sale of the product.

The estimated operating costs for both lagoon and raceway aquaculture systems are presented in Table 9. The higher operating costs for lagoons is attributable primarily to the increased difficulty of fish handling procedures during harvest, and to additional disease treatment costs because of the larger surface area. While the need for disease treatment is a variable for actual operations, the assumption here is that, on the average, a chemical disease treatment will be required once a year and is therefore included as an annual operating cost.

The cost of stock by species for each strategy is presented in Table 10, and Table 11 shows the cost of stock, by species, for a polyculture system. The polyculture column in Table 10 is the total column from Table 11. It is evident that the cost of stocking is an extremely variable element, ranging from a low of $11 for bigmouth buffalo in

## TABLE 9

## ESTIMATED AQUACULTURE OPERATING COSTS EXCLUDING STOCK

| Expenditure Category | Raceway | | Lagoon | |
|---|---|---|---|---|
| General-- | | | | |
| Fish Culturist, 1/4 time including disease analysis | $3,000 | | $3,000 | |
| Laborer, daily care, including D.O. and pH analysis | 1,584 | | 1,584 | |
| Disease Treatment | 440 | | 1,320 | |
| Vehicle, $ .10/mile @ 1,000 miles/yr. | 200 | | 200 | |
| Materials and Supplies (screws, land tools, buckets, etc.) | 150 | | 150 | |
| Subtotal | | $5,374 | | $6,254 |
| Stocking, excluding species | | | | |
| Transporting, 100 miles @ .50/mi. | 50 | | 50 | |
| Laborer, 1 man/day | 24 | | 24 | |
| Prophylactic Disease Treatment | 25 | | 25 | |
| Subtotal | | $ 99 | | $ 99 |
| Harvesting | | | | |
| Seines[1] | 100 | | 250 | |
| Miscellaneous Supplies | 100 | | 100 | |
| Disease Chemicals | 50 | | 50 | |
| Labor[2] | 144 | | 600 | |
| Vehicle, @ .20/mi. | 10 | | 20 | |
| Subtotal | | $ 404 | | $1,020 |
| TOTAL | | $5,877 | | $7,373 |

[1] 2100' seines for raceway and 1500' seine for lagoon, amortized for three years.

[2] 6 man/days of labor for raceway, 25 man/days for lagoon, both exclude fish culturist accounted for in general category.

## TABLE 10

## ESTIMATED COST OF STOCK FOR MONOCULTURE BY STRATEGY AND SPECIES

| Strategy | Carp[1] | Buffalo[2] | Channel Catfish[3] | Goldfish[4] | Fathead Minnows[5] | Golden Shiner[6] | Polyculture[7] |
|---|---|---|---|---|---|---|---|
| 1 | $98 | $72 | $3,135 | $396 | $125 | $129 | $4,880 |
| 2 | 98 | 72 | 3,135 | 396 | 125 | 129 | 4,880 |
| 3 | 98 | 72 | 3,135 | 396 | 125 | 129 | 4,880 |
| 4 | 46 | 34 | 1,488 | 264 | 100 | 103 | 1,536 |
| 5 | 45 | 33 | 1,440 | 264 | 100 | 103 | 1,607 |
| 6 | 33 | 24 | 1,047 | 264 | 100 | 103 | 1,205 |
| 7 | 32 | 23 | 1,020 | 264 | 100 | 103 | 1,179 |
| 8 | 14 | 11 | 465 | 264 | 100 | 103 | 610 |
| 9 | 14 | 10 | 441 | 264 | 100 | 103 | 585 |
| 13 | 33 | 24 | 1,047 | 264 | 100 | 103 | 1,205 |
| 14 | 32 | 23 | 1,020 | 264 | 100 | 103 | 1,177 |

[1] 3-5" Carp Fingerling, $ .05 each, 10/lb., $ .50/lb.
[2] 3-5" Buffalo Fingerling, $.05 each, 10/lb., .50/lb.
[3] 3" Catfish Fingerling, $.03 each, 1000/lb., $30.00/lb.
[4] Adult Fish, $1.75/lb.
[5] Adult Fish, $1.65/lb.
[6] Adult Fish, $1.70/lb.
[7] Total stocking cost for all species, see Table 11.

## TABLE 11

## ESTIMATED COST OF STOCK FOR POLYCULTURE BY STRATEGY AND SPECIES*

| Strategy | Golden Shiner[1] | Channel Catfish[2] | Goldfish[3] | Buffalo[4] | Largemouth Bass[5] | Bluegill[6] | Total |
|---|---|---|---|---|---|---|---|
| 1 | $1,283 | $3,114 | $396 | $71 | $8 | $8 | $4,880 |
| 2 | 1,283 | 3,114 | 396 | 71 | 8 | 8 | 4,880 |
| 3 | 1,283 | 3,114 | 396 | 71 | 8 | 8 | 4,880 |
| 4 | 103 | 1,368 | 26 | 34 | 1 | 4 | 1,536 |
| 5 | 103 | 1,440 | 26 | 33 | 1 | 4 | 1,607 |
| 6 | 103 | 1,047 | 26 | 24 | 1 | 4 | 1,205 |
| 7 | 103 | 1,020 | 26 | 25 | 1 | 4 | 1,179 |
| 8 | 103 | 465 | 26 | 11 | 1 | 4 | 610 |
| 9 | 103 | 441 | 26 | 10 | 1 | 4 | 585 |
| 10 | 103 | 1,047 | 26 | 24 | 1 | 4 | 1,205 |
| 11 | 103 | 1,020 | 26 | 23 | 1 | 4 | 1,177 |

[1] Adult Fish, $1.70/lb.

[2] 3" Fingerlings, 3¢ each, 1000/lb., $30.00/lb.

[3] Adult Fish, $1.75/lb.

[4] 3-5" Fingerlings, 5¢ each, 10/lb., $ .50/lb.

[5] 2" Fingerlings, 2¢ each, 200/lb., $4.00/lb.

[6] 1" Fingerlings, 1¢ each, 1000/lb., $10.00/lb.

*Price per lb. x numbers of lbs. required. See Table 6.

Strategy 8 to a high of $4,880 for Polyculture stock in Strategies 1, 2, and 3. Stocking costs were derived from the stocking rates in Tables 3 and 4, which are based on the projected outputs. In estimating the Polyculture stock costs the assumption was made that small quantities of some species, i.e. bass and bluegill, could be purchased at the prices specified in the footnotes at the bottom of Table 10. To the extent that this assumption might not hold, the figures presented may underestimate the cost of stocking.

Table 12 presents the estimated annual net revenues from the sale of aquaculture output. Net revenues are the estimated revenues in the previous section, Table 7, minus the cost of stock from Table 10. Net revenues from Polyculture exceed those from all other species for every strategy. The monoculture with the highest net revenue is channel catfish. Hence, from the aspect of net revenue generation, a Polyculture system contributes more to an overall cost reduction for treatment systems than does any of the single systems. However, since catfish are fairly close in forms of revenue generating ability, and since catfish markets are the most highly developed as are the techniques associated with their production, it is reasonable to consider catfish as a viable species with excellent potential for use in an aquaculture system. However, the biota which develops in the typical wastewater system is not suitable for the production of channel catfish to a size larger than 6"-8", and the market for this size fish may be limited.

Table 13 summarizes the annual net revenues for both Polyculture and catfish production and lists present value of the discounted income streams for a 20-year period. These are the (R) values contained in

## TABLE 12

## ESTIMATED ANNUAL NET REVENUES FROM AQUACULTURE
(Revenue minus cost of stock)

| Strategy | Carp | Buffalo | Channel Catfish | Goldfish | Fathead Minnows | Golden Shiner | Polyculture |
|---|---|---|---|---|---|---|---|
| 1 | $653 | $578 | $20,410 | $15,729 | $3,309 | $4,298 | $20,749 |
| 2 | 653 | 578 | 20,410 | 15,729 | 3,309 | 4,298 | 20,749 |
| 3 | 653 | 578 | 20,410 | 15,729 | 3,309 | 4,298 | 20,749 |
| 4 | 310 | 275 | 9,682 | 7,377 | 1,527 | 2,002 | 10,616 |
| 5 | 299 | 266 | 9,373 | 7,126 | 1,471 | 1,286 | 10,150 |
| 6 | 218 | 192 | 6,808 | 5,116 | 1,045 | 1,376 | 7,342 |
| 7 | 213 | 181 | 6,630 | 4,984 | 1,022 | 1,342 | 7,151 |
| 8 | 97 | 86 | 3,020 | 2,128 | 405 | 557 | 3,185 |
| 9 | 91 | 82 | 2,874 | 2,022 | 382 | 521 | 3,004 |
| 13 | 218 | 192 | 6,808 | 5,116 | 1,045 | 1,376 | 7,341 |
| 14 | 213 | 188 | 6,630 | 4,984 | 1,022 | 1,342 | 7,153 |

## TABLE 13

## DISCOUNTED VALUES FOR ANNUALIZED STREAM OF NET REVENUES BY STRATEGY FOR SPECIES YIELDING THE HIGHEST NET REVENUES*

| Strategy | | | Annual Net Revenues | 20-Year Discounted Stream |
|---|---|---|---|---|
| 1 | a. | Catfish | $20,410 | $236,552 |
| | b. | Polyculture | $20,749 | $240,481 |
| 2 | a. | Catfish | 20,410 | 236,552 |
| | b. | Polyculture | 20,749 | 240,481 |
| 3 | a. | Catfish | 20,410 | 236,552 |
| | b. | Polyculture | 20,749 | 240,481 |
| 4 | a. | Catfish | 9,682 | 112,214 |
| | b. | Polyculture | 10,616 | 123,039 |
| 5 | a. | Catfish | 9,373 | 108,633 |
| | b. | Polyculture | 10,150 | 117,639 |
| 6 | a. | Catfish | 6,808 | 78,905 |
| | b. | Polyculture | 7,342 | 85,094 |
| 7 | a. | Catfish | 6,630 | 76,842 |
| | b. | Polyculture | 7,151 | 82,880 |
| 8 | a. | Catfish | 3,020 | 35,002 |
| | b. | Polyculture | 3,185 | 36,914 |
| 9 | a. | Catfish | 2,874 | 33,310 |
| | b. | Polyculture | 3,004 | 34,816 |
| 13 | a. | Catfish | 6,808 | 78,905 |
| | b. | Polyculture | 7,347 | 85,082 |
| 14 | a. | Catfish | 6,630 | 76,842 |
| | b. | Polyculture | 7,153 | 82,903 |

*In all cases, the system yielding the highest net revenue is the polyculture system followed by a monoculture of channel catfish.

These are the only systems shown since, under the assumptions of this study, these are the only economical alternatives. To calculate the discounted stream for other species, multiply the net revenues from Table 12 by a factor of 11.59.

the cost summaries in Table 8. For these two cultures the revenues generated are highly significant and reduce substantially the costs of treatment construction and operation.

Caution is necessary in applying the aquaculture cost and revenue data presented. All such data were estimated from the biological parameters and revenue parameters presented in the section on aquaculture. All of the data deficiencies discussed in those sections apply to the data presented here. The very tentative nature of the estimated production capabilities of aquaculture makes the aquaculture revenue data tentative, and hence, must be used as a first estimate of the probable magnitude of the economic viability of these systems for wastewater treatment. In addition, water quality parameters have not been firmly established for aquaculture systems by good, scientifically controlled experiments.

There are certain factors in selecting water treatment strategies that are not quantifiable in monetary terms, but are still of great importance in any decision-making process. Quantitative data compiled with qualitative considerations will delineate the alternatives more fully.

These non-monetary factors were compiled by the project's consulting engineer in consultation with the biologist. Seven non-monetary cost factors were considered of importance, and each was ranked on a scale of one to ten, from minimum to maximum impact. The factors considered were 1) land requirements, 2) susceptibility to climatic variations, 3) effect on the system of industrial pollutants, 4) reliability of the process, 5) ease of operation and maintenance, 6) air pollution generated, and 7) waste pollutant by-products. Table 14 presents the ranking of these non-monetary considerations.

## COST-EFFECTIVE SYSTEMS

In the analysis of cost-effective strategies, multiple objective levels defining alternative water quality parameters were established. The first objective level is stated in terms of declining levels of five day biochemical Oxygen demand ($BOD_5$) and Suspended Solids (SS). The second objective level is defined in terms of declining levels of nutrients in the form of Phosphorus (P) and TKN Nitrogen. The multiple objective level approach was deemed desirable because current secondary treatment standards are defined in terms of $BOD_5$ and SS without reference to nutrient levels. Currently, waste water treatment systems are meeting secondary standards when $BOD_5 \leq 30$ mg/l, and SS $\leq 30$ mg/l. The assumption is made that future standards for advanced treatment systems will, in part, be defined with respect to P and N levels. For the various strategies under consideration there is not a single coefficient for all pollutant reduction. Some stages of the treatment strategies influence levels of a given pollutant but does not reduce others. As a result, the multiple objective level approach was adopted.

Table 15 presents the most cost-effective aquaculture system and conventional system (or stage) for achieving objectives A through F in $BOD_5$ and Suspended Solids reduction. In addition, the total discounted costs of operating the system are presented, and the cost of the aquaculture system (where applicable) is expressed as a percentage of the cost of the conventional system.

## TABLE 14

## NON-MONETARY FACTORS ASSOCIATED WITH EACH STAGE

| Stage | Land Requirement | Climatic Variation | Effects of Industrial Pollutants | Reliability of Process | Ease of Operation & Maintenance | Air Pollution Generated | Waste Pollutant By-Products |
|---|---|---|---|---|---|---|---|
| $X_1$ | 1 | 2 | 1 | 1 | 3 | 2 | 10 |
| $X_2$ | 10 | 9 | 10 | 2 | 2 | 1 | 1 |
| $X_3$ | 5 | 1 | 3 | 2 | 6 | 1 | 4 |
| $X_4$ | 6 | 1 | 3 | 2 | 3 | 1 | 5 |
| $X_5$ | 5 | 1 | 3 | 1 | 5 | 1 | 2 |
| $X_6$ | 5 | 4 | 3 | 4 | 5 | 6 | 3 |
| $X_7$ | 2 | 1 | 1 | 1 | 6 | 1 | 4 |
| $X_8$ | | | | | | | |
| $X_9$ | 10 | 6 | 4 | 2 | 10 | 3 | 3 |
| $X_{10}$ | | | | | | | |
| $X_{11}$ | 10 | 8 | 6 | 10 | 6 | 1 | 1 |
| $X_{12}$ | | | | | | | |
| $X_{13}$ | | | | | | | |
| $X_{14}$ | | | | | | | |
| $X_{15}$ | | | | | | | |

Ranked on a scale of 1 to 10, from minimum to maximum.

## TABLE 15

## COST EFFECTIVE SYSTEMS TO ACHIEVE ALTERNATIVE OBJECTIVE LEVELS OF $BOD_5$ AND SUSPENDED SOLIDS (SS)

| Alternative Objectives* | Aquaculture | Cost, Aquaculture % of Conventional | Conventional |
|---|---|---|---|
| Objective A<br>$BOD_5 \le 30$, $SS \le 30$ | Strategy 2<br>$187,987 | 28% | $X_5$<br>Ext.Aeration<br>$681,907 |
| Objective B<br>$BOD_5 \le 25$, $SS \le 26.25$ | Strategy 2<br>$187,987 | 28% | $X_5$<br>Ext.Aeration<br>$681,907 |
| Objective C<br>$BOD_5 \le 20$, $SS \le 22.5$ | Strategy 14<br>$726,957 | 62% | $X_4$ Act.Sludge<br>Chemical Add.<br>$1,168,256 |
| Objective D<br>$BOD_5 \le 15$, $SS \le 18.75$ | Strategy 14<br>$726,957 | 52% | $X_7$ Coagulation Filtra.<br>$1,396,750 |
| Objective E<br>$BOD_5 \le 10$, $SS \le 15$ | Strategy 13<br>$783,046 | 56% | $X_7$ Coagulation Filtra.<br>$1,396,750 |
| Objective F<br>$BOD_5 \le 5$, $SS \le 7$ | None | -- | $X_8$<br>Carb. Sorp.<br>$3,087,326 |

*mg/l.

The most cost-effective system to meet objective A (current secondary treatment standards) is Strategy 2, a Waste Stabilization Lagoon with an Aquaculture lagoon. Costs for the Strategy 2 Aquaculture system are only 28 percent of the costs of achieving that level of water quality by the most cost-effective conventional system (extended aeration) although both these systems also meet objective B.

In all cases, when an aquaculture system is capable of achieving a given $BOD_5$ and SS objective, the aquaculture strategy is the most cost-effective. Not only is the aquaculture the most cost-effective, but in every case the cost differential between the aquaculture strategy and the conventional strategy is substantial. The minimum savings associated with aquaculture are found for objective C, where aquaculture costs are 62 percent of conventional costs, and the maximum cost saving is achieved for objectives A and B (28 percent of conventional costs). Under the assumptions of this study there is no aquaculture system that can achieve objective F. However, theoretically aquaculture systems should be able to reduce all plant nutrients and this limitation of aquaculture probably reflects the methodology of this study plus the lack of knowledge with respect to removal efficiency. Data is unavailable to substantiate this capability of aquaculture. Only stage four ($X_8$) of the conventional strategy 12 can reduce BOD5 and SS to such low levels, and then only at a staggering cost of more than three million dollars. This, of course, indicates that the potential savings from aquaculture might be massive if future research shows that aquaculture can, in fact, reduce BOD and SS to the levels defined in objective F.

A similar cost-effective ranking of strategies is obtained when the Phosphorus/TKN objectives are employed. These comparisons are presented in Table 16. Strategy 2, a Waste Stabilization Lagoon with an Aquaculture Lagoon is the most cost-effective strategy for all objectives with the exception of D. Again, data on water quality are insufficient to allow an exact determination of TKN values and therefore it is currently unknown, using the methodology employed in this study, whether or not any of the alternative aquaculture systems will meet a TKN $\leq$ 3. Strategy 2 will reduce P to 1.3 mg/l and will thus meet the requirements of objective D, but must be rejected as a result of the TKN unknown (see Table 5). The only strategy that meets those stringent levels of nutrient removal is strategy 12 at a cost of $3,315,383.

The cost saving associated with the use of aquaculture relative to conventional methods for nutrient reduction are even more significant than for BOD/suspended solids reduction. For objectives B and C, the cost of aquaculture represents only 6 percent of the cost of achieving that level of nutrient reduction using the most cost-effective conventional system. This differential is striking and indicates the potential of aquaculture for low cost nutrient reduction.

For objective A a Stabilization Lagoon with an Aquaculture Lagoon is more cost-effective than simply the Stabilization Lagoon by itself. This outcome is obtained because the Aquaculture Lagoon generates enough revenue to recoop part of the costs of building and operating the Stabilization Lagoon. This cost-effective ranking is therefore dependent upon the revenues received from the sale of aquaculture products.

## TABLE 16

## COST EFFECTIVE SYSTEMS TO ACHIEVE ALTERNATIVE OBJECTIVE LEVELS OF PHOSPHORUS AND TKN*

| Alternative Objectives** | Aquaculture | Cost, Aquaculture % of Conventional | Conventional |
|---|---|---|---|
| Objective A<br>$P \le 9$, $TKN \le 13$ | Strategy 2<br>\$187,987 | 62% | $X_2$ Waste Stabilization L.<br>\$300,515 |
| Objective B<br>$P \le 7$, $TKN \le 9$ | Strategy 2<br>\$187,987 | 6% | Strategy 12<br>\$3,315,383 |
| Objective C<br>$P \le 5$, $TKN \le 5$ | Strategy 2<br>\$187,987 | 6% | Strategy 12<br>\$3,315,383 |
| Objective D<br>$P \le 3$, $TKN \le 3$ | None | -- | Strategy 12<br>\$3,315,383 |

*TKN values for aquaculture are unknown, but always assumed to be less than Total N values which are known.

**mg/l.

It is useful to note that the least expensive system (strategy 3, where fish are grown directly in the Stabilization Lagoon) is rejected for all objectives because of high suspended solids (SS = 70.9) which fail to meet current secondary treatment standards. In addition, it is felt that this strategy is extremely susceptible to biological disruption, especially oxygen depletion, and is therefore not capable of providing a reliable treatment process.

The most cost-effective alternative becomes much less clear when the BOD/suspended solids objectives are combined with the P/TKN objectives. Through personal conversations with Mr. Coleman, Assistant Deputy Commissioner for Environmental Health Services, Oklahoma State Department of Health, a perspective tertiary treatment level was set up. This level was defined at $BOD_5 \leq 10$, Suspended Solids $\leq 15$, Phosphorus $\leq 5$, and TKN $\leq 5$. Table 17 presents a classification of effluent quality by stage and strategy with respect to primary, secondary, and tertiary treatment levels. A (Y) indicates that the minimum pollutant level requirement is met or exceeded, and an (X) indicates that the particular pollutant is greater than defined by the standard and is therefore a limiting factor and prevents achievement of that standard.

All strategies, with the exception of strategy 3, meet secondary standards with strategy 2 as the most cost-effective. Tertiary treatment levels, on the other hand, are only met by strategy 12, and perhaps by strategies 8 and 9, although an exact estimate of TKN is unavailable for the aquaculture stages. This is not an insignificant factor, however, since the costs for the conventional strategy 12 ($3,315,383)

## TABLE 17

## CLASSIFICATION AND ANALYSIS OF EFFLUENT QUALITY

| | Secondary Treatment | | | | | Tertiary Treatment | | | |
|---|---|---|---|---|---|---|---|---|---|
| Strategy | $BOD_5 \leq 30$ | $SS \leq 30$ | P | TKN | Total N | $BOD_5 \leq 10$ | $SS \leq 15$ | $P \leq 5$ | $TKN \leq 5$* |
| No. 1 | | | | | | | | | |
| Stage I ($X_2$) | X | X | Y | Y | Y | X | X | Y | X |
| Stage II ($X_{11}$) | Y | Y | Y | Y | Y | X | X | Y | Y |
| No. 2 | | | | | | | | | |
| Stage I ($X_2$) | X | X | Y | Y | Y | X | X | Y | X |
| Stage II ($X_{12}$) | Y | Y | Y | Y | Y | X | X | Y | Y |
| No. 3 | | | | | | | | | |
| Stage I ($X_2$) | Y | X | Y | Y | Y | X | X | Y | X |
| No. 4 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_6$) | Y | X | Y | Y | Y | X | X | X | X |
| Stage III ($X_1$[illegible]) | Y | Y | Y | Y | Y | X | X | X | X |
| No. 5 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_6$) | Y | X | Y | Y | Y | X | X | X | X |
| Stage III ($X_{12}$ | Y | Y | Y | Y | Y | X | X | X | X |
| No. 6 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_3$ | Y | Y | Y | Y | Y | X | X | X | X |
| Stage III ($X_{11}$) | Y | Y | Y | Y | Y | Y | Y | X | X |
| No. 7 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_3$) | Y | Y | Y | Y | Y | X | X | X | X |
| Stage III ($X_{12}$) | Y | Y | Y | Y | Y | Y | X | Y | X |

X = Limiting Factor Y = Non-Limiting Factor

*TKN considered non-limiting only when Total N = the TKN requirement

TABLE 17--Continued

| Strategy | Secondary Treatment | | | | | Tertiary Treatment | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $BOD_5 \leq 30$ | $SS \leq 30$ | P | TKN | Total N | $BOD_5 \leq 10$ | $SS \leq 15$ | $P \leq 5$ | $TKN \leq 5$* |
| No. 8 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_4$) | Y | Y | Y | Y | Y | X | X | Y | X |
| Stage II ($X_{11}$) | Y | Y | Y | Y | Y | Y | Y | Y | X |
| No. 9 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | Y | X |
| Stage II ($X_4$) | Y | Y | Y | Y | Y | X | X | Y | X |
| Stage III ($X_{12}$ | Y | Y | Y | Y | Y | Y | Y | Y | X |
| No. 10 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_3$) | X | X | Y | Y | Y | X | X | X | X |
| Stage III ($X_9$) | Y | Y | Y | Y | Y | X | X | X | Y |
| No. 11 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_3$) | Y | Y | Y | Y | Y | X | X | X | X |
| Stage III ($X_7$) | Y | Y | Y | Y | Y | Y | Y | Y | X |
| No. 12 | | | | | | | | | |
| Stage I ($X_1$) | X | X | Y | Y | Y | X | X | X | X |
| Stage II ($X_3$) | Y | Y | Y | Y | Y | X | X | X | X |
| Stage III ($X_7$) | Y | Y | Y | Y | Y | Y | Y | Y | X |
| Stage IV ($X_8$) | Y | Y | Y | Y | Y | Y | Y | Y | X |
| Stage V ($X_{10}$) | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| No. 13 | | | | | | | | | |
| Stage I ($X_5$) | Y | Y | Y | Y | Y | X | X | X | X |
| Stage II ($X_{11}$) | Y | Y | Y | Y | Y | Y | Y | X | X |
| No. 14 | | | | | | | | | |
| Stage I ($X_5$) | Y | Y | Y | Y | Y | X | X | X | X |
| Stage II ($X_{12}$) | Y | Y | Y | Y | Y | Y | X | Y | X |
| No. 15 | | | | | | | | | |
| Stage I ($X_2$) | X | X | Y | Y | Y | X | X | Y | X |
| Stage II ($X_7$) | Y | Y | Y | Y | Y | Y | Y | Y | X |

are more than double the costs of the aquaculture strategies 8 and 9 ($1,311,386 and $1,261,393 respectively). Again, substantiation of removal efficiencies for aquaculture systems is critical for ascertaining the most cost-effective strategy. Because of this lack of knowledge strategies 8 and 9 must be currently rejected as alternatives to achieve tertiary treatment levels. Thus, strategy 12, an activated sludge plant with coagulation filtration, carbon sorption, and ammonia removal is the only strategy capable of meeting the tertiary definition and hence is cost-effective.

Unfortunately, the most cost-effective systems for nutrient removal (strategies 2 and 1) are limited in $BOD_5$ and Suspended Solids reduction. The latter is reduced to 25.4 mg/l and the former to 12.5 mg/l--both above the levels required for tertiary classification. This "trade-off" problem between the BOD/Suspended Solids complex and the nutrient complex is typical of the water quality analysis of the various strategies examined in this study. The most cost-effective system for a particular municipality will therefore be a function of both the composition of influent and the nature of the receiving waters. Where the major problem area is associated with nutrients, the Stabilization Lagoon with an aquaculture system is by far the most efficient system. When the major area of concern is with BOD/suspended solids more advanced mechanical/aquaculture strategies are most cost-effective (i.e., strategy 13), even though these systems are less efficient at nutrient reduction.

The reason strategies 1 and 2 are so efficient at nutrient reduction, relative to the more advanced aquaculture systems, is that the

Stabilization Lagoon itself reduces P by 55 percent and TKN by 67 percent before the effluent enters the fish lagoon or raceway. In contrast, the nutrient levels in the effluent entering the aquaculture stages in the more advanced systems is still very high. Therefore, since the aquaculture stages of the more advanced strategies have more nutrients to remove the overall nutrient reduction by those strategies tends to be less than that achieved in strategies 1 and 2.

Table 18 shows the efficiency of the various strategies in terms of the percentage reduction for the five types of pollutants. The percentage reduction figures allow for a comparison among strategies as to cost vs. efficiency. Table 19 ranks the strategies with respect to total costs, by stage.

Throughout this report it has been emphasized that much of the aquaculture data is tentative in nature and is, of course, dependent upon the assumptions made. As a result, even though it is felt that all of the assumptions made result in conservative estimates, the possibility exists that the estimates bias the cost-effectiveness outcome in favor of aquaculture--especially given the very large cost differences relative to conventional systems presented in Table 15 and Table 16. Since those cost estimates are made on the basis of the "most optimistic" net revenues generated (polyculture systems), estimates should also be made on the basis of the "most pessimistic" possible net revenues generated. These estimates are presented in the second cost column of Table 19.

## TABLE 18

## CUMULATIVE PERCENT REDUCTION OF POLLUTANTS, BY STRATEGY AND STAGE*

| Pollutant | No. 1 | | No. 2 | | No. 3 | No. 4 | | | No. 5 | | | No. 6 | | | No. 7 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_2$ | $X_{11}$ | $X_2$ | $X_{12}$ | $X_2$ | $X_1$ | $X_6$ | $X_{11}$ | $X_1$ | $X_6$ | $X_{12}$ | $X_1$ | $X_3$ | $X_{11}$ | $X_1$ | $X_3$ | $X_{12}$ |
| BOD5 | 81 | 94 | 81 | 94 | 88 | 33 | 86 | 93 | 33 | 86 | 95 | 33 | 90 | 95 | 33 | 90 | 97 |
| Suspended Solids | 59 | 88 | 59 | 88 | 69 | 52 | 85 | 92 | 52 | 85 | 90 | 52 | 89 | 94 | 52 | 89 | 93 |
| Phosphorus (as P) | 55 | 83 | 55 | 88 | 73 | 9 | 18 | 27 | 9 | 18 | 52 | 9 | 27 | 35 | 9 | 27 | 57 |
| TKN (as N) | 67 | | 67 | | | 0 | 3 | | 0 | 3 | | 0 | 3 | | 0 | | |
| Total N (as N) | 63 | 84 | 63 | 86 | 71 | 0 | 0 | 33 | 0 | 0 | 37 | 0 | 0 | 33 | 0 | 0 | 37 |

*Assumes raw influent of $BOD_5$ = 210 mg/1, suspended solids = 230 mg/1, total phosphorus (as P) = 11 mg/1, TKN (as N) = 30 mg/1, and Total N (as N) = 30 mg/1.

TABLE 18--Continued

| Pollutant | No. 8 | | | No. 9 | | | No. 10 | | | No. 11 | | | No. 12 | | | | | No. 13 | | No. 14 | | No. 15 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_4$ | $X_{11}$ | $X_1$ | $X_4$ | $X_{12}$ | $X_1$ | $X_3$ | $X_9$ | $X_1$ | $X_3$ | $X_7$ | $X_1$ | $X_3$ | $X_7$ | $X_8$ | $X_{10}$ | $X_5$ | $X_{11}$ | $X_5$ | $X_{12}$ | $X_2$ | $X_7$ |
| $BOD_5$ | 33 | 90 | 95 | 33 | 90 | 97 | 33 | 81 | 93 | 33 | 90 | 96 | 33 | 90 | 95 | 98 | 98 | 90 | 95 | 90 | 97 | 81 | 95 |
| Suspended Solids | 52 | 91 | 95 | 52 | 91 | 94 | 52 | 85 | 93 | 52 | 89 | 98 | 52 | 89 | 98 | 99 | 99 | 89 | 94 | 89 | 93 | 59 | 98 |
| Phosphorus (as P) | 9 | 82 | 84 | 9 | 82 | 89 | 9 | 18 | 27 | 9 | 27 | 95 | 9 | 27 | 90 | 93 | 93 | 27 | 35 | 27 | 57 | 55 | 91 |
| TKN (as N) | 0 | 3 | | 0 | | | 0 | 0 | 97 | 0 | 3 | 3 | 0 | 3 | 3 | 3 | 93 | 0 | | 0 | | 67 | 67 |
| Total N (as N) | 0 | 0 | 33 | 0 | 0 | 37 | 0 | 0 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 90 | 0 | 33 | 0 | 37 | 63 | 63 |

## TABLE 19

## RANK ORDER OF STRATEGIES BY CUMULATIVE COSTS AND STAGES

| | Strategy | | Costs with Positive Aquaculture Net Revenues | % Reduction in Costs from Aquaculture | Costs with Zero Aquaculture Net Revenues |
|---|---|---|---|---|---|
| 3 | Waste Stabilization Lagoon with Fish | | $300,515 | | |
| | | $X_2$ | 145,487 | 62% | $385,968 |
| 2 | Waste Stabilization Lagoon with Aquaculture Lagoon | $X_2$ | 300,515 | | |
| | | $X_{12}$ | 187,987 | 56% | 428,468 |
| 1 | Waste Stabilization Lagoon with Aquaculture Raceway | $X_2$ | 300,515 | | |
| | | | 240,078 | 50% | 480,559 |
| 14 | Extended Aeration with Aquaculture Lagoon | $X_5$ | 681,907 | | |
| | | $X_{12}$ | 726,957 | 10% | 809,860 |
| 13 | Extended Aeration with Aquaculture Raceway | $X_5$ | 681,907 | | |
| | | $X_{11}$ | 776,869 | 10% | 861,951 |
| 5 | Trickling Filter with Aquaculture Lagoon | $X_1$ | 404,683 | | |
| | | $X_6$ | 947,413 | | |
| | | $X_{12}$ | 957,727 | 11% | 1,075,366 |
| 4 | Trickling Filter with Aquaculture Raceway | $X_1$ | 404,683 | | |
| | | $X_6$ | 947,413 | | |
| | | $X_{11}$ | 1,004,418 | 11% | 1,127,457 |
| 7 | Activated Sludge with Aquaculture Lagoon | $X_1$ | 383,071 | | |
| | | $X_3$ | 1,138,960 | | |
| | | $X_{12}$ | 1,184,033 | 7% | 1,266,913 |
| 6 | Activated Sludge with Aquaculture Raceway | $X_1$ | 383,071 | | |
| | | $X_3$ | 1,138,960 | | |
| | | $X_{11}$ | 1,233,910 | 7% | 1,319,004 |

TABLE 19--Continued

| Strategy | | Costs with Positive Aquaculture Net Revenues | % Reduction in Costs from Aquaculture | Costs with Zero Aquaculture Net Revenues |
|---|---|---|---|---|
| 9 Activated Sludge, Chemical Addition with Aquaculture Lagoon | $X_1$ | $340,633 | | |
| | $X_4$ | 1,168,256 | | |
| | $X_{12}$ | 1,261,393 | 3% | $1,296,209 |
| 8 Activated Sludge, Chemical Addition with Aquaculture Raceway | $X_1$ | 350,633 | | |
| | $X_4$ | 1,168,256 | | |
| | $X_{11}$ | 1,311,386 | 3% | 1,348,300 |
| 15 Waste Stabilization Lagoon with Coagulation Filtration | $X_2$ | 301,674 | | |
| | $X_7$ | 1,428,961 | | |
| 10 Activated Sludge, Denitrification System | $X_1$ | 385,544 | | |
| | $X_3$ | 1,024,149 | | |
| | $X_9$ | 1,759,313 | | |
| 11 Activated Sludge with Coagulation Filtration System | $X_1$ | 375,974 | | |
| | $X_3$ | 1,293,515 | | |
| | $X_7$ | 2,401,865 | | |
| 12 Activated Sludge with Carbon Sorption, Ammonia Removal System | $X_1$ | 375,974 | | |
| | $X_3$ | 1,293,575 | | |
| | $X_7$ | 2,325,865 | | |
| | $X_8$ | 3,087,326 | | |
| | $X_{10}$ | 3,315,383 | | |

The assumption upon which the most pessimistic estimates are made is that net revenues from the aquaculture system are zero. This implies that revenue from the sale of aquaculture products is just equal to the cost of the stock. There is, consequently, no cost reduction in construction and operating outlays through the generation of positive revenues from the aquaculture systems.

It is significant that in each case, while the total cost of the aquaculture system increases, the relative cost ranking of the strategies is unchanged. This implies that those systems which are cost-effective with positive net revenues are also cost-effective with zero net revenues. The one exception to this is for objective A in Table 16 when the Waste Stabilization Lagoon without an Aquaculture system becomes more cost-effective than the Stabilization Lagoon with an Aquaculture system. Since potential revenues do not influence the cost-effective decision in strategy selection, except as indicated above, the major benefits from aquaculture systems stem from the ability of such systems to improve water quality relative to costs of treatment.

In addition, this analysis indicates that aquaculture systems cannot be expected to "pay" the cost of treating water and may, therefore, be economically unfeasible for private enterprise operations, although certain private contractual arrangements might be possible. In fact, Table 19 also shows the percent reduction in costs that can potentially be gained from aquaculture revenues. It should be clear, however, that the economic value of aquaculture is in cost savings relative to conventional systems and not in the market value of the aquatic output.

And this remains the case even when net revenues are zero. Aquaculture systems, therefore, should be considered as a treatment system for achieving water quality standards at minimum cost.

# DISCUSSION

## WORK PERFORMED

The research on this project required an interdisciplinary approach and the research team was comprised of a biologist, an engineer, and two economists. The engineering work for the project was subcontracted to the engineering firm, Settle, Dougall, and Spear of Oklahoma City, and the majority of the engineering work was performed by Mr. George McBryde, Sanitary Engineer, Oklahoma State Department of Health. The biologist, Mr. Ron Jarman, Supervisor of Aquaculture projects, Oklahoma State Department of Health, was employed part-time on the project by Central State University, Edmond, Oklahoma. Both economists, Dr. Upton B. Henderson, and Dr. Frank S. Wert, are members of the faculty of Central State University, Department of Economics, Edmond, Oklahoma.

Coordination of the project was accomplished under the direction of the principle investigator, Dr. Henderson, through frequent informal meetings of the research team. Methodology, strategy design and selection, and all data requirements were established, reviewed, and approved by all researchers. Therefore, consistency with economic cost-effective methodology was assured in gathering the biological, engineering, and economic data needed for the study.

The engineering subcontractor was responsible for providing consultation on relevant waste water treatment strategy delineation and for determining the technical effectiveness, in terms of water quality, of the conventional treatment systems selected. In addition, in consultation with the project's biologist, the engineer established the engineering design parameters for the aquaculture raceway and lagoon systems and provided cost data for the various strategies selected for cost-effectiveness analysis.

All estimates of fish production, aquaculture water quality parameters, and the technology of aquaculture were the responsibility of Mr. Ron Jarman, the project's fisheries biologist. The data on this aspect of the study were generated from pilot aquaculture projects in the State of Oklahoma which have been conducted under the auspices of the Oklahoma State Department of Health and from additional literature sources. In addition, the biologist established resource requirements and estimated costs for the operation and maintenance of aquaculture systems.

The economic analysis, research design, revenue estimations, project administration, and final report preparation were carried out by Central State University, Department of Economics. The basic tasks performed by the two research economists were the construction of the cost-effectiveness model and the determination of basic engineering, biological, and technical water quality data needed for the model. Estimates of revenues were made and the market potential for aquaculture products was determined. All data was collected, analyzed, interpreted, and presented in final form by the project's economists.

## PROBLEM AREAS

The methodology of cost-effectiveness is basically a simple theoretical framework and is well accepted as a tool of public decision making. The model requires certain types of data and precision in definitions of goals. The application to conventional waste water treatment strategy is well documented. However, its application to aquaculture as an additional or alternative waste water treatment strategy poses many problems. The lack of an adequate data base, at this stage of the development of aquaculture technology, constitutes the major problem in employing cost-effectiveness methodology. Water quality efficiencies and aquaculture production capabilities are not well documented in the scientific literature.

These data deficiencies limit the outcome of this study. Problems in biological, economic, and to a lesser degree in engineering data tend to weaken the project's tentative findings. As a better data base on waste water aquaculture becomes available, the usefulness of applying this model to assess the economic viability of aquaculture treatment systems will increase, thereby enhancing a rational decision making process.

The estimation of biological data constituted the major research problem which had to be overcome in the study. There is no reliable information from controlled studies on the relative efficiency of varying species of fish and polyculture in terms of water quality. Most of the literature in the field of aquaculture is concerned with fish production and marketing, but water quality has not been a major consideration in these studies. Variation in water quality may result from different retention rates, seasonal variation in species, species composition, nutrient loading, and size of fish when harvested.

In addition, actual yields from a waste water aquaculture system may be a function of water quality variation. Well monitored and controlled experiments of aquaculture systems are needed to strengthen the data base in this field. Health considerations, production, and water quality must be more firmly established before the economic feasibility of aquaculture is determined with a high degree of certainty.

The economic data base on this study is also weak in terms of projected estimates of net revenues derived from aquaculture systems. Good marketing data and research on market acceptability is lacking in the literature on waste water aquaculture systems. No data is available on products derived from waste water aquaculture products in this country when water quality is the prime consideration. Public acceptance of the technology,as well as the resulting output, is another consideration which must be researched.

The opportunity cost of the nutrients derived from waste water in terms of an array of outputs is unknown. Recreational benefits as well as commercial products could be derived from these projects. An integrated "mechanical-natural systems" approach might yield optimum water quality and possibly a wide array of various types of outputs. Man-made marshes, land recycling, aquaculture lakes and lagoons in an integrated system may be highly feasible, low cost, water treatment alternatives. Such systems may yield recreational benefits (i.e., waterfowl habitat, fishing, etc.), commercial products (timber, cattle, and commercial fish production), and may result in energy conservation. This study only considers a very narrow range of alternatives within the confines of traditional methods of water treatment.

Available engineering data on water quality could also be strengthened. Better monitoring of seasonal variations is needed to accurately assess the problems and potentials of aquaculture. The nation's goal for water quality in the future will have a great bearing on the feasibility of aquaculture as a waste water treatment facility. As concluded in this study, aquaculture appears to be a more attractive cost-effective alternative if standards require plant nutrient reductions before release to surface waters. Net energy savings and reduced marginal costs of meeting more stringent standards of water quality appear to be highly probable.

As a result of the problems discussed above, the conclusions reached in this report must be interpreted as tentative. Substantiation of these conclusions must await a more adequate and accurate data base.

## SUMMARY AND CONCLUSIONS

This study attempted to ascertain the economic viability of aquaculture as an alternative treatment system to achieve mandated water quality standards. The emphasis was placed on small municipalities which face major financial barriers to achieve the nation's commitment to clean water.

A cost-effectiveness model was utilized. This model allowed comparisons of varying water quality standards and the use of technically feasible alternative treatment strategies to achieve these standards in terms of costs.

Conventional and aquaculture systems were selected on the basis of technical feasibility. Water quality standards and the effectiveness of conventional systems to achieve these goals were determined from secondary source material of previous studies conducted under the auspices of the Environmental Protection Agency and data obtained from monitoring studies of this type of treatment system in the State of Oklahoma. The effectiveness of aquaculture to obtain given reductions in the level of pollutants was obtained from a single demonstration project conducted in Oklahoma (Quail Creek).

Potential production of fish and bait products from aquaculture were determined on the basis of the assumption that production from a waste water lagoon would be equal to fertilized fish culture ponds. Potential revenues from production were determined on the basis of current price quotes received from commercial fish culturists in three Southwestern states.

All cost estimates for conventional waste water treatment systems were derived from standard engineering cost publications. Cost estimates and design of aquaculture systems were provided by the consulting engineer and the biologist. These systems were designed to facilitate fish culturist practices. The selection of species and the species composition of polyculture were delineated on the basis of previous research. The results of this research supports the suitability for rearing aquatic animals in sewage waste water aquaculture systems. Variation in water quality and susceptibility to biological disruption, as it relates to the selection of species, was not determined in this study.

Fifteen (15) technically feasible sewage treatment strategies were examined. Aquaculture raceways were incorporated into five (5) strategies as the last stage in the total treatment process and lagoon aquaculture systems were used in an additional six (6) strategies. The remaining four strategies were solely mechanical-chemical conventional treatment systems at all stages in the process of water treatment. All strategies were then analyzed to determine the most cost-effective systems.

A standard present value approach to all annual costs and revenues was used, and a discount rate of 5-7/8 percent, as recommended for water development and related projects, was employed. The present value of the net cost of each stage of each strategy was determined. EPA cost-effective guidelines were employed.

The economic analysis of the various strategies was first based on multiple objective levels for $BOD_5$ and suspended solids, with secondary treatment standards as the minimum objective. A second multiple objective level of water quality was defined in terms of plant nutrient removal. Finally, a tertiary treatment objective was defined for all pollutants considered. The various strategies were examined in terms of their ability to meet various reduction levels for pollutants and accepted or rejected on the basis of relative costs.

When the ability to reduce suspended solids and $BOD_5$ was considered aquaculture strategies were always more cost-effective than the corresponding conventional alternatives when aquaculture was capable of achieving the desired level of BOD5/SS removal. There were significant and substantial differences in cost in every case, with cost differentials between aquaculture and conventional strategies ranging from a low of 3.8 percent to a high of 72 percent.

When nutrient removal was established as a goal of treatment, again aquaculture alternatives were cost reducing relative to conventional systems when aquaculture was capable of achieving stated P/TKN objectives. The cost differentials between conventional and aquaculture strategies for those objectives ranged from a low of 38 percent to a high of 94 percent. When aquaculture was not capable of meeting a given objective it was, of course, deemed not to be cost-effective. In those cases, however, the inability of aquaculture probably reflects lack of knowledge as to water quality parameters from aquaculture systems as well as lack of knowledge relative to the technology of water treatment processes by those systems.

This study concludes that Strategy 2 Waste Stabilization Lagoon with an Aquaculture Lagoon is the most cost-effective system to meet current secondary standards. As a result of the aquaculture unknowns for advanced treatment processes, the most cost-effective system to meet tertiary levels is Strategy 12 Activated Sludge plant with Carbon Sorption, Ammonia Removal. The system was cost-effective, however, only because no other strategy was capable of meeting such high levels of water quality.

The potential revenue generated from aquaculture was not critical to the economic analysis in terms of a cost-effective decision model. The reduction in costs from the adaption of an Aquaculture alternative was less dramatic when zero net revenues were assumed, but the relative cost ranking of the strategies remained the same. Aquaculture waste water alternatives appears to be economically attractive regardless of the market for products if, in fact, such systems achieve the water quality levels indicated by the conservative estimates made in this study.

At this stage of our knowledge aquaculture waste water treatment systems are economically viable alternatives. The potential for waste water aquaculture systems to achieve even better water quality is very high, and is probably species dependent and related to water retention time in the aquaculture system, plus the length of the food chain established. These facets of aquaculture should be determined as quickly as possible since this study has shown the great potential for cost reduction. The susceptibility to biological disruptions related to temperature variation could possibly be overcome with a polyculture designed to function under most climatic conditions within a given region. Possibly seasonal rotation of the composition of the polyculture species could resolve this difficulty. Again, this knowledge would improve the economic viability of waste water treatment aquaculture systems.

The potential of waste water aquaculture systems to produce usable products is obviously larger than immediate markets for stocking and minnows for bait purposes. In an increasingly crowded world the production of protein from low energy and low land intensive technology will become increasingly more attractive from an economic point of view. Higher prices for fossil fuels and land will shift economic advantages away from current agriculture practices. The more efficient converters of plant energy typically found in aquatic systems, coupled with zero priced nutrients in municipal waste water to produce plant energy, has great economic potential for the future. Sewage treatment plants are long-term investments by society and future markets can be expected to make aquaculture an even more attractive technology for the treatment of municipal waste water.

This study represents a "first attempt" to quantify the potential economic relationships associated with aquaculture as a waste treatment technology. Although the study raises as many questions as it answers, wastewater aquaculture is definitely a low cost alternative to conventional treatment technology and, it is felt should be given serious consideration at this time as an economically feasible treatment system.

# BIBLIOGRAPHY

Allen, George H. "The Constructive Use of Sewage, with Particular Reference to Fish Cultures," FAO Technical Conference in Marine Pollution and Its Effect on Living Resources and Fishing. (Rome 9/18, December, 1970) F.I.R.: MP/70/R-13.

________. "A Preliminary Bibliography on the Utilization of Sewage in Fish Culture." FAO Fisheries Circular, No. 308, March, 1969.

________, and Balfour Hepher. "Recycling of Wastes Through Aquaculture and Constraints to Wider Application." Unpublished paper, 1976.

________, and Larry Dennis. Report on Pilot Aquaculture System Using Domestic Waste Waters for Rearing Pacific Salmon Smolts. Wastewater Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C. Report No. EPA 660/2-74-041, June, 1974, pp. 162-198.

Altman, R. W. "Investigate Before You Invest." Proceedings, Oklahoma State University, Fish Farming Conference, 1970.

Bailey, W. M., F. P. Meyer, J. M. Martin and D. L. Gray. "Farm Fish Production in Arkansas During 1972," Proceedings, 27th Annual Conference, S. E. Association, Game and Fish Commission, 1973, pp. 750-757.

Carpenter, R. LeRoy, Mark S. Coleman and Ron Jarman. "Aquaculture as an Alternative Waste Water Treatment System." Unpublished manuscript, 1975.

________, Harold K. Malone, Ara F. Roy, Aaron L. Mitchum, Herbert E. Beauchamp and Mark S. Coleman. "The Evaluation of Microbial Pathogens in Sewage and Sewage-Grown Fish." Waste Water Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C. Report No. EPA 660/2-74-041, June, 1974, pp. 46-55.

Clemens, H. P. "Some Comments on Production, Harvesting, and Marketing of Channel Catfish in Oklahoma." Oklahoma State University, Fish Farming Conference, 1970, pp. 22-28.

Coleman, Mark S., J. P. Henderson, H. G. Chichester, and R. L. Carpenter. "Aquaculture as a Means to Achieve Effluent Standards." Waste Water Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C. Report No. EPA 660/2-74-041, June, 1974, pp. 199-214.

________, and R. Jarman. "Comparative Role of Non-Point Sources and Municipal Wastes in the Eutrophication of Oklahoma Reservoirs." Unpublished manuscript, 1975.

"Cost Effective Analysis." Appendix A to 40 CFR, part 35, Federal Register, Vol. 38, No. 174, September 10, 1973.

Cost-Effective Waste Water Treatment Systems. Final Report, U. S. Environmental Protection Agency, Office of Water Operations, Washington, D. C., 1975.

Davidson, Paul, F. G. Adams, and J. Seneca. "The Social Value of Water, Recreational Facilities Resulting From an Improvement in Water Quality, The Delaware Estuary." Kneese and Smith, eds., Water Research, Johns Hopkins Press, Baltimore, 1966, pp. 175-224.

Demonstrated Technology and Research Needs for Reuse of Municipal Waste Water. Cincinnati, Ohio, National Environmental Research Center, E.P.A., May, 1975.

DiGregorio, David, et al. Cost of Waste Water Treatment Processes. Cincinnati: U. S. Department of the Interior, December, 1968.

Dinges, R. Ecology of Daphnia in Stabilization Ponds. Texas State Department of Health Publication, 1973, 155 pp.

________. The Availability of Daphnia for Water Quality Improvement and as an Animal Food Source. Waste Water Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C., Report No. EPA 660/2-74-041, June, 1974, pp. 142-161.

________. "Biological Consideration in Stabilization Pond Design." Paper presented at 56th Texas Water Utilities Short School, Texas A & M University, 1974, 17 pp.

________, and A. Rust. "The Role of Daphnia in Waste Water Oxidation Ponds." Public Works, October, 1972, pp. 89-91.

Dobie, J., O. L. Meechan, S. F. Sniezko, and G. H. Washburn. "Raising Bait Fishes." Circular 35, U. S. Department of Interior, 1957.

Donaszy, Erno. Principles of Sewage Treatment Through Utilization in Fish Ponds. Waste Water Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C., Report No. EPA 660/2-74-041, June, 1974, pp. 546-556.

Duffer, William R. "Lagoon Effluent Solids Control by Biological Harvesting." Symposium on Upgrading Waste Water Stabilization Ponds to Meet New Discharge Standards. Environmental Protection Agency and Utah State University, (Mimeographed Report), August, 1974.

Eilers, Richard G. Condensed One-Page Estimates for Waste Water Treatment. Cincinnati: Environmental Protection Agency, November, 1970.

Ehrlich, S. "Two Experiments in the Biological Clarification of Stabilization Pond Effluents." Hydrobiologia (Israel), 27: 80-90, 1966.

Environmental Protection Agency. Evaluation of Municipal Sewage Treatment Alternatives--Final Report. Washington, D. C., February, 1974.

Environmental Protection Agency. A Guide to the Selection of Cost Effective Waste Water Treatment Systems, EPA 430/9-74-002, Washington, D. C., July, 1975.

Freeman, A. Myrick, III, Robert H. Haveman, and Allen V. Kneese. The Economics of Environmental Policy. New York: John Wiley & Sons, Inc. , 1973.

Gosselink, James G., Eugene P. Odum, and R. M. Pope. The Value of the Tidal Marsh. Gainesville, Fla.: Urban and Regional Development Center , May, 1973.

Greer, D. E., and C. D. Ziebell. "Biological Removal of Phosphates from Water." J. Water Pollution Control Federation. 44, 12: 2342-2348, 1972.

Hallock, R. J. and C. D. Ziebell. "Feasibility of a Sport Fishery in Tertiary Treated Waste Water." J. Water Pollution Control Federation. 42:1656-1665.

Hepher, B. "Supplementary Feeding in Fish Cultures." Separatum. Switzerland, 1972.

Hinesly, T. D. Water Renovation for Unrestricted Re-Use.

Huggins, Thomas G. and Roger W. Bachmann. Production of Channel Catfish in Tertiary Treatment Ponds. Iowa State Water Resources Research Institute, Ames, Iowa, June, 1969.

Huguenin, John E. and John H. Ryther. "Experiences with a Marine Aquaculture-Tertiary Sewage Treatment Complex." Waste Water Use in the Production of Food and Fiber--Proceedings. Environmental Protection Agency, Washington, D. C. Report No. 660/2-74-041. June, 1974, pp. 377-386.

Kneese, A. V., R. U. Ayres, and R. C. d'Arge. Economics and the Environment: A Materials Balance Approach. Resources for the Future, Washington, D. C., 1970

Kneese, Allen V., and Stephen C. Smith, eds. Water Research. Baltimore: Johns Hopkins Press, 1966 , pp. 175-224.

Konefes, John L. and Roger W. Bachmann. "Growth of the Fathead Minnow in Tertiary Treatment Ponds." Proceedings, Iowa Academy of Science, 77:104-111, 1970.

Las Virgenes Municipal Water District, Calabassas, California. "Tertiary Treatment with Controlled Ecological System." Environmental Protection Agency, Washington, D. C. Report No. EPA 660/2-73-022. December, 1973, 43 pp.

Mackenzie, C. R. and G. D. Campbell. "Hygenic Evaluation of the Food Fish Tilapia melanopleura and Tilapia mossambica Nurtured in Sewage Effluent." S. A. Medical Journal, September, 1973, p. 968.

Manual of Instruction for Sewage Treatment Plant Operators. Albany, New York: Health Education Service, prepared by New York State Department of Health.

Marsden, J. R., D. E. Pingry, and S. Whinston. Economics of Waste Water Treatment: The Role of Regression. Office of Water Resources Research, Washington, D. C.

McMichael, Walter F. Cost of Dissolved Air Flotation Thickening of Waste Activated Sludge at Municipal Sewage Treatment Plants. Cincinnati: National Environmental Research Center, February, 1974.

________. Costs of Hauling and Land Spreading of Domestic Sewage Treatment Plant Sludge. Cincinnati: National Environmental Research Center, February, 1974.

McShan, Michael, Norman M. Trieff, and Dov Grajcer. "Biological Treatment of Waste Water Using Algae and Artemia." Journal of Water Pollution Control Federation, 46(7):1742-1750, July, 1974.

Methodology for Economic Evaluation of Municipal Water Supply/Waste Water Disposal Including Considerations of Seawater Distillation and Waste Water Renovation. San Francisco: Bechtel Corporation, August, 1970.

Meyer, F. P., D. L. Gray, W. P. Mathis, J. M. Martin and B. R. Wells. "Production and Returns from the Commercial Production of Fish in Arkansas During 1966." Proceedings, 21st Annual Conference of S. E. Association of Game and Fish Commission, pp. 525-531.

________, D. S. Godwin, R. Boyd, J. M. Martin, D. L. Gray, and W. P. Mathis. "Fish Production in Arkansas During 1969 as Compared to Other States." Proceedings, 24th Annual Conference of S. E. Association of Game and Fish Commission, 1970, pp. 497-506.

Mihursky, J. A. "On Using Industrial and Domestic Waste in Aquaculture. Agriculture Engineering, November, 1969, pp. 667-669.

Oklahoma Commercial Fishery Statistics, 1974. Federal Aid Project No. 2-240-K-1, Oklahoma Department of Fish and Game, Oklahoma City, September 2, 1975.

Patterson, W. L., *et al*. *Estimating Costs and Manpower Requirements for Conventional Waste Water Treatment Facilities*. Washington, D. C.: National Technical Information Service, U. S. Department of Commerce, October, 1971.

Peskin, Henry M. and Eugene P. Seskin, eds. *Cost Benefit Analysis and Water Pollution Policy*. Washington, D. C.: The Urban Institute, 1975.

Porter, J. Winston, *et al*. *Cost Estimating Guidelines for Waste Water Treatment Systems*. San Francisco: Bechtel Corporation, July, 1970.

Prather, E. E. "Experiments on the Commercial Production of Golden Shiners." *Proceedings, 10th Annual Conference of S. E. Game and Fish Commission*, pp. 150-155, 1957.

Prather, E. E., J. R. Fielding, H. S. Swingle, and M. C. Johnson. "Production of Bait Minnows in the Southeast." Circular 112, Agricultural Experiment Station, Alabama Polytechnic Institute, 1954.

Reid, G. W. "Algae Removal by Fish Production." *Proceedings of Water Resources*, Symposium No. 9, University of Texas Press, Austin, Texas, 1976, p. 417-421.

*Retail Market Potential for Farm Cultured Catfish*. Agricultural Experiment Station, Bulletin 799, University of Arkansas, Fayetteville, Arkansas, May, 1975.

Rytler, J. H. "The Use of Flowing Biological Systems in Aquaculture." *Sewage Treatment, Pollution Assay and Food Chain Studies*. WHOI-73-2, 1973.

Sawyer, C. N. Basic Concepts of Eutrophication. *Journal of Water Pollution Control Federation*. 38:737-744, 1966.

Sawyer, C. N., J. B. Lackey, and A. T. Lenz. "Investigations of the Odor Nuisance Occurring in the Madison Lakes, particularly Lakes Monona, Waubeas, and Kegonsa from July, 1943 to July, 1944." Report of the Governor's Commission, State of Wisconsin.

Schaat, W. E. "Fish Population Models: Potential and Actual Links to Ecological Models."

Schroder, Gerald L. "Some Effects of Stocking Fish in Waste Treatment Ponds." *Water Research*. Great Britain, The Pergamon Press, 1975.

Singer, Neil M. *Public Microeconomics*. Boston: Little & Brown, 1972. Chapter 12.

Smith, Robert. *A Compilation of Cost Information for Conventional and Advanced Waste Water Treatment Plant and Processes*. Cincinnati: Robert A. Taft Sanitary Engineering Center, December, 1967.

________, and Walter F. McMichael. *Cost and Supply Analysis for Alum and Methanol Used in Waste Water Treatment*. Cincinnati: Environmental Protection Agency, National Technical Information Service, August, 1971.

________. *Cost-Effectiveness Analysis for Water Pollution Control*. Cincinnati: National Environmental Research Center, Office of Research and Development, Environmental Protection Agency, August, 1974.

________. *Cost and Performance Estimates for Tertiary Waste Water Treating Processes*. Cincinnati: Federal Water Pollution Control Administration, June, 1966.

________, *et al*. *Costs of Waste Water Renovation*. Cincinnati: Environmental Protection Agency, November, 1971.

________. *The Cost of Dispersed Floc Nitrification and Denitrification for Removal of Nitrogen from Waste Water*. Cincinnati: Environmental Protection Agency, November, 1970.

________, and Richard G. Eilers. *Waste Water Treatment Plant Cost Estimating Program Documentation*. Cincinnati: Environmental Protection Agency, Water Quality Office, March, 1973.

Steele, John H. *The Structure of Marine Ecosystems*. Harvard University Press, 1974.

Swingle, H. S. "Experiments on Growing Fingerling Channel Catfish to Marketable Size in Ponds." *Proceedings, 12th Annual Conference of S. E. Association of Game and Fish Commission*, pp. 63-72, 1958.

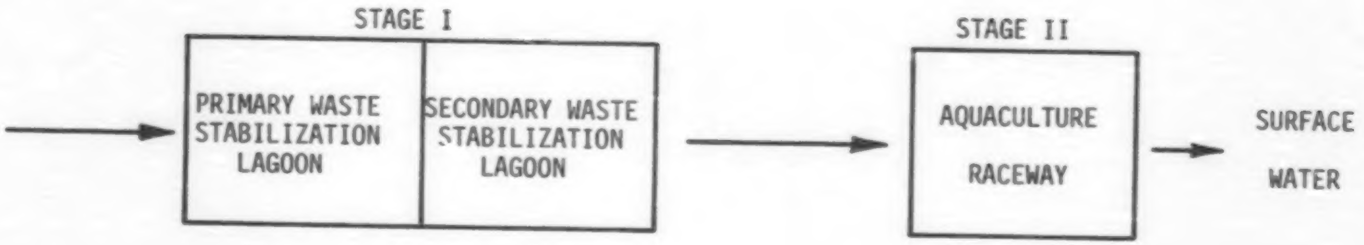
Tannenbau, Stillings, and Schrimshaw, eds. *The Economics, Marketing and Technology of Fish Protein Concentrate*. Cambridge, Mass.: The M. I. T. Press, 1974.

Trimberger, J. "Production of Fathead Minnows (*Pimephales Promelas*) in a Municipal Waste Water Stabilization System." Michigan Department of Natural Resources, Fisheries Division. (Mimeographed Report), 1972, 5 pp.

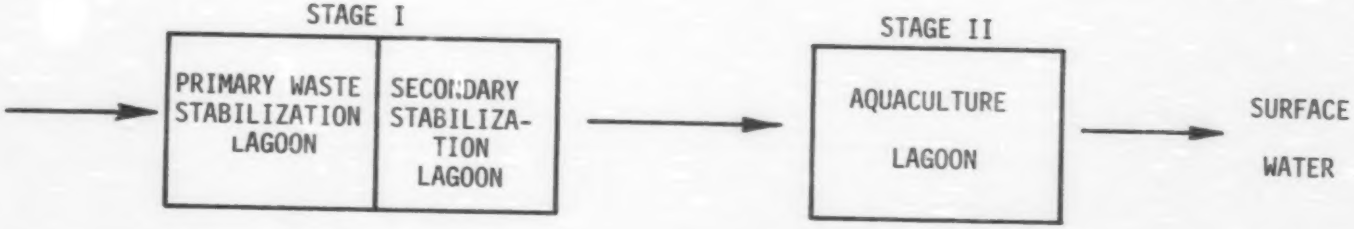
United States Department of Commerce. *A Statistical Reporting System for the Catfish Farming Industry, Methodology and 1970 Results*. Washington, D. C.: U. S. Government Printing Office, 1972.

# APPENDIX

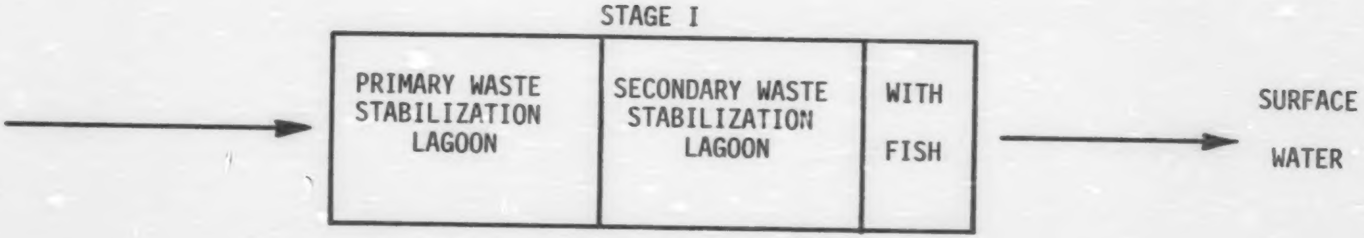
# SCHEMATIC PRESENTATION OF TREATMENT STRATEGIES


STAGE I
PRIMARY WASTE STABILIZATION LAGOON
SECONDARY WASTE STABILIZATION LAGOON
STAGE II
AQUACULTURE RACEWAY
SURFACE WATER

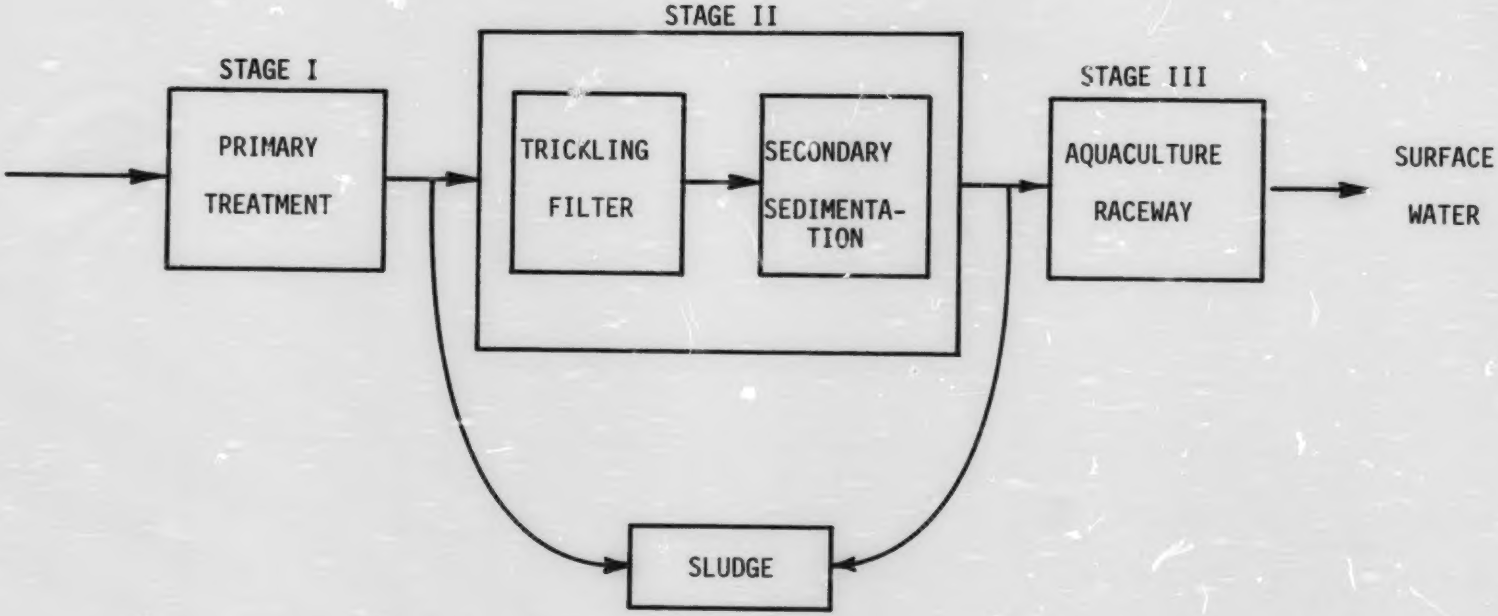
STRATEGY NO. 1 -- WASTE STABILIZATION LAGOON WITH AQUACULTURE


STAGE I
PRIMARY WASTE STABILIZATION LAGOON
SECONDARY STABILIZATION LAGOON
STAGE II
AQUACULTURE LAGOON
SURFACE WATER

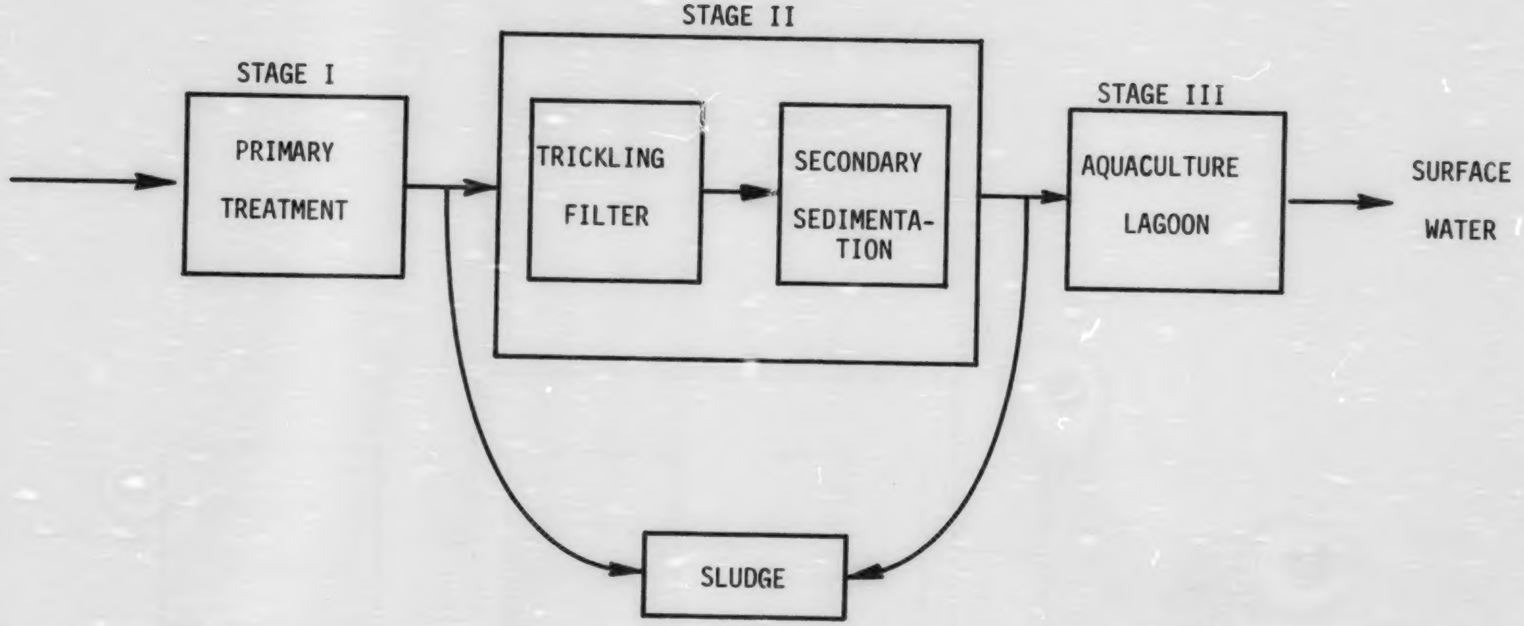
STRATEGY NO. 2 -- WASTE STABILIZATION LAGOON WITH AQUACULTURE LAGOON


STAGE I
PRIMARY WASTE STABILIZATION LAGOON
SECONDARY WASTE STABILIZATION LAGOON
WITH FISH
SURFACE WATER

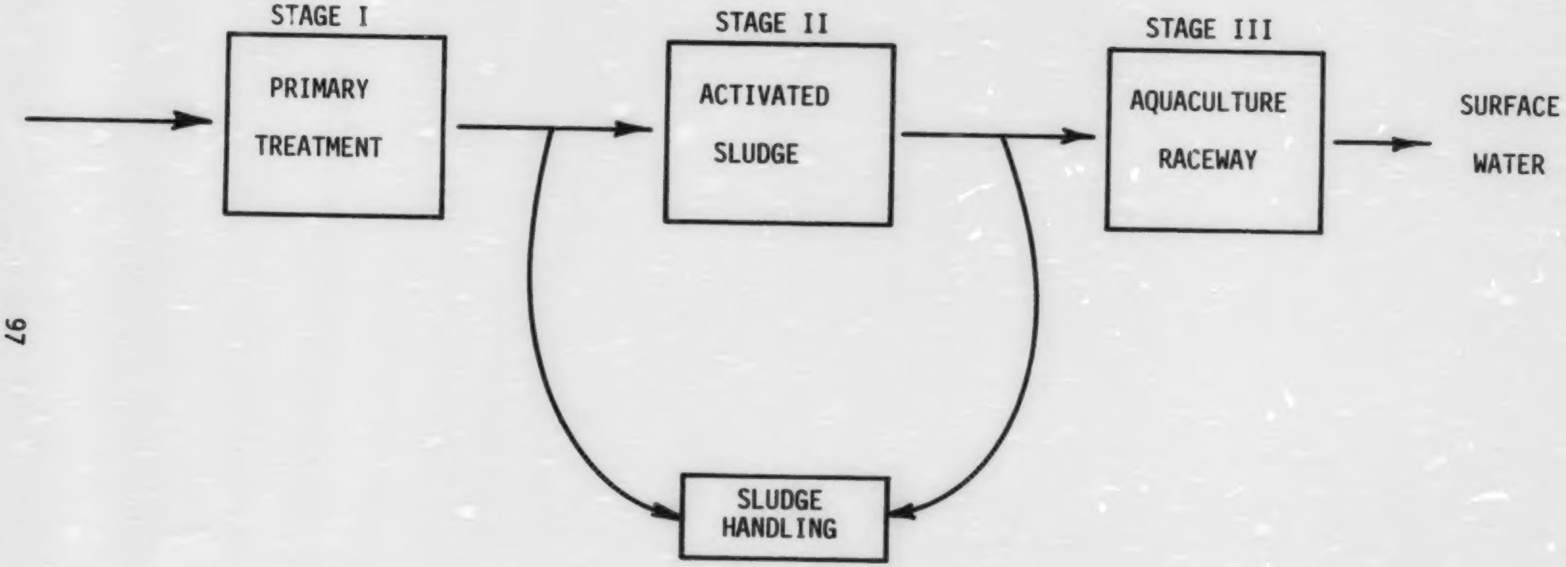
STRATEGY NO. 3 -- WASTE STABILIZATION LAGOON WITH FISH


STAGE I
PRIMARY
TREATMENT
STAGE II
TRICKLING
FILTER
SECONDARY
SEDIMENTA-
TION
STAGE III
AQUACULTURE
RACEWAY
SURFACE
WATER
SLUDGE

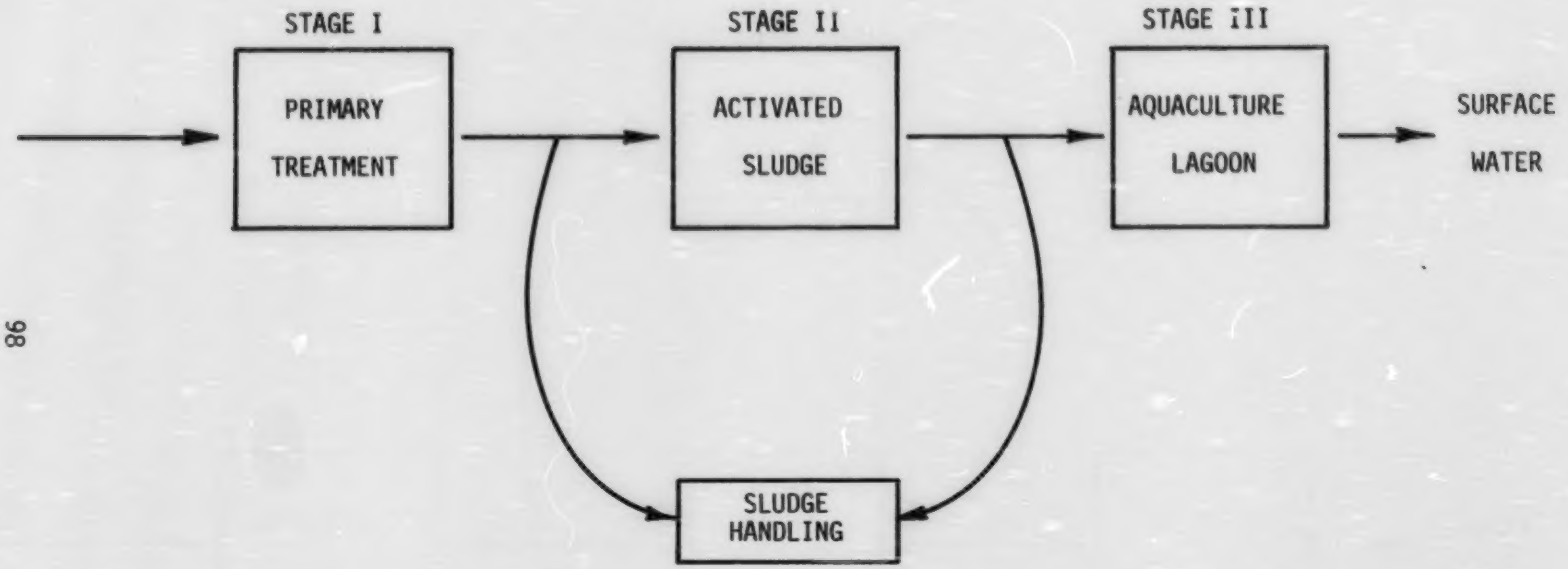
STRATEGY NO. 4 -- TRICKLING FILTER WITH AQUACULTURE RACEWAY


STAGE I
PRIMARY
TREATMENT
STAGE II
TRICKLING
FILTER
SECONDARY
SEDIMENTA-
TION
STAGE III
AQUACULTURE
LAGOON
SURFACE
WATER
SLUDGE

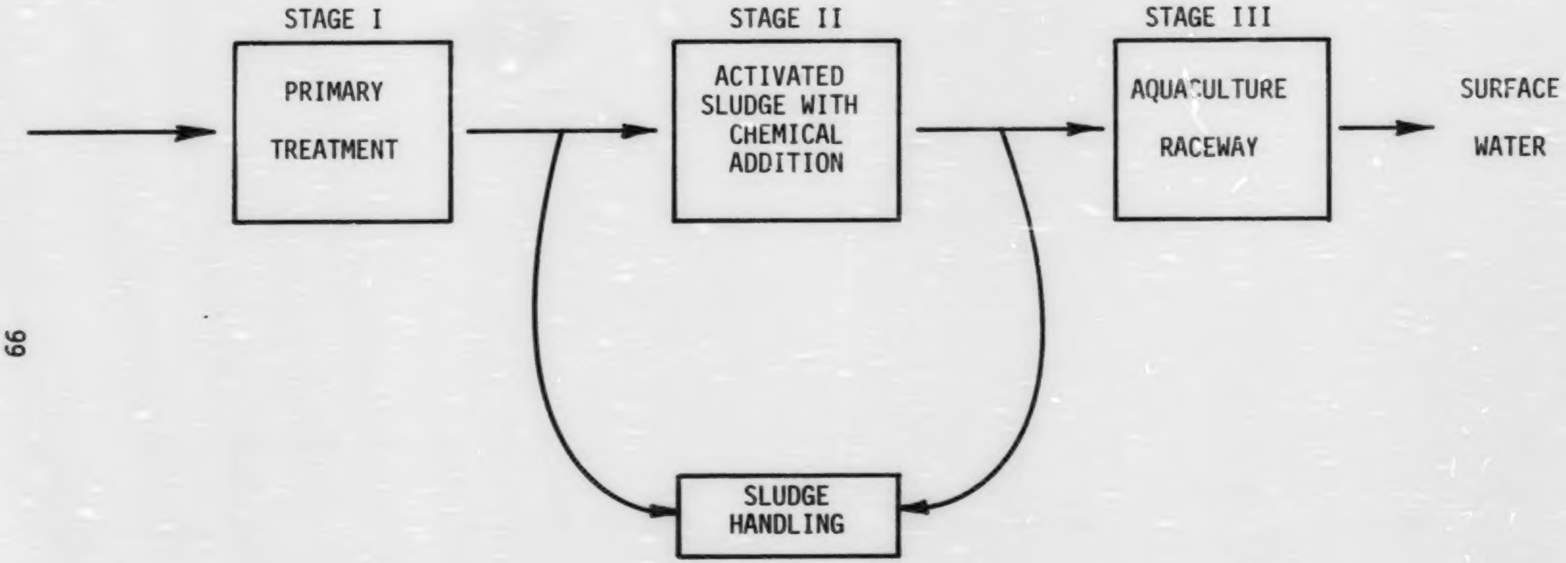
STRATEGY NO. 5 -- TRICKLING FILTER WITH AQUACULTURE LAGOON


STAGE I
PRIMARY
TREATMENT
STAGE II
ACTIVATED
SLUDGE
STAGE III
AQUACULTURE
RACEWAY
SURFACE
WATER
SLUDGE
HANDLING

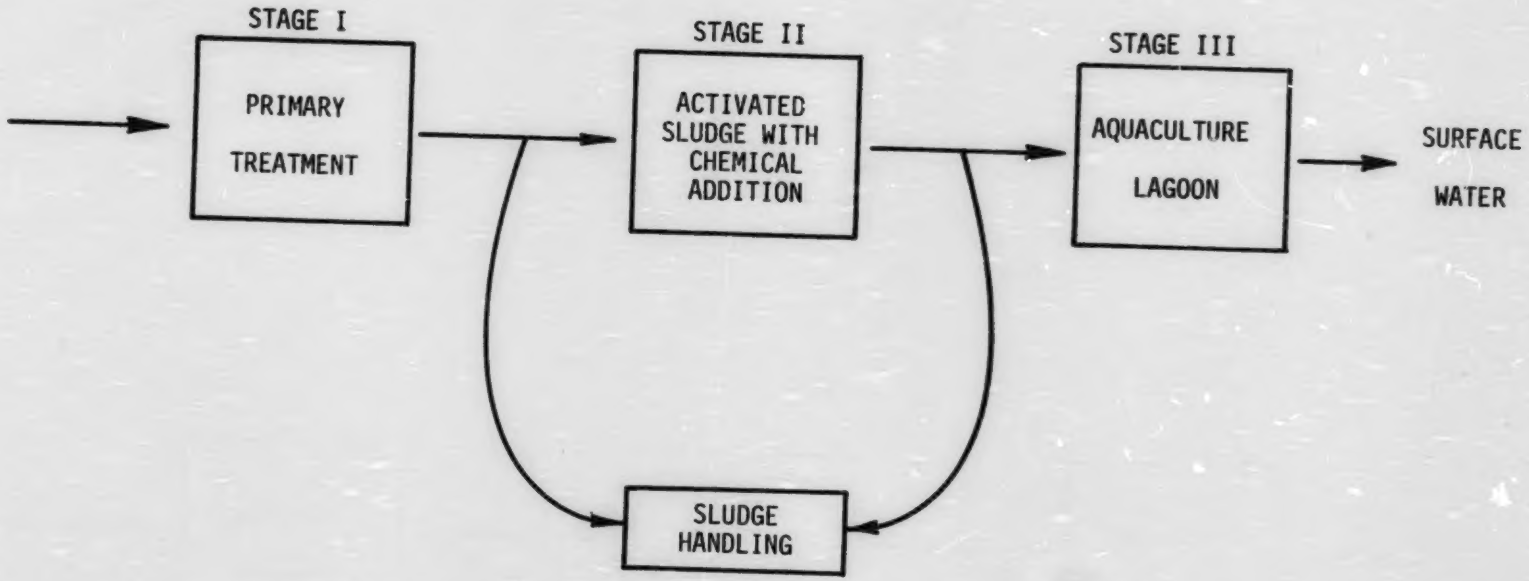
STRATEGY NO. 6 -- ACTIVATED SLUDGE WITH AQUACULTURE RACEWAY


STAGE I
PRIMARY TREATMENT
STAGE II
ACTIVATED SLUDGE
STAGE III
AQUACULTURE LAGOON
SURFACE WATER
SLUDGE HANDLING

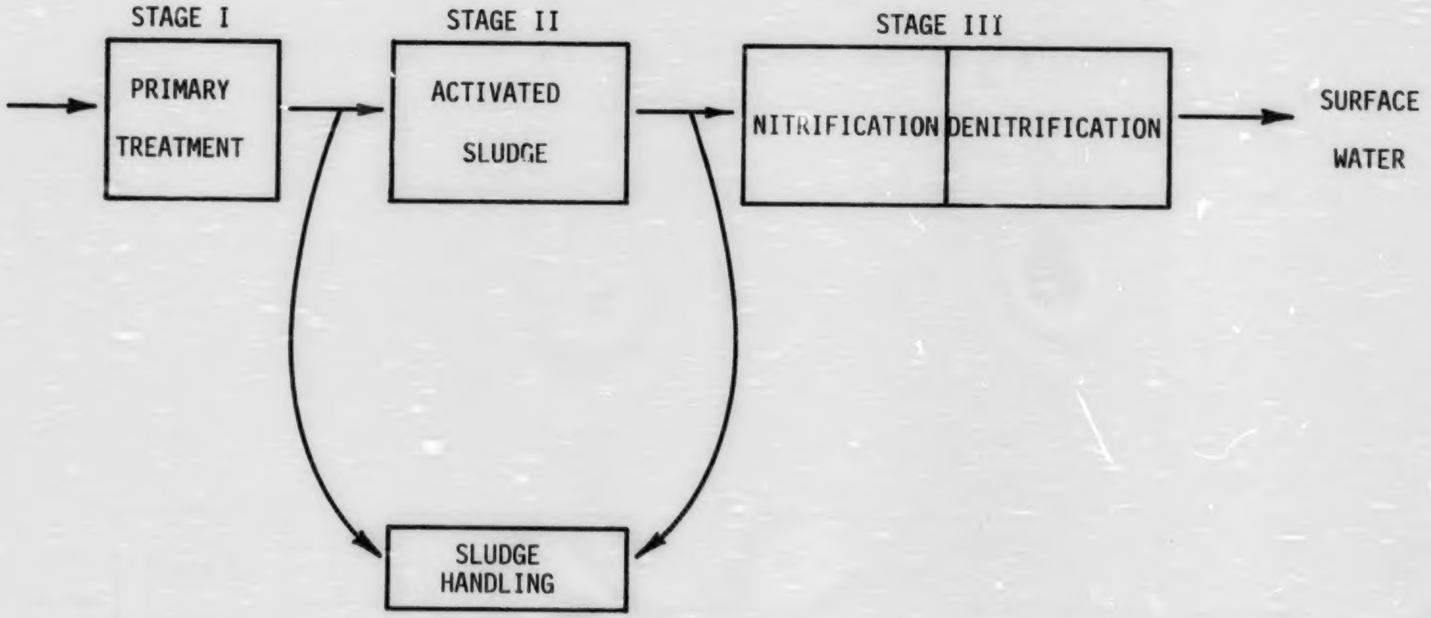
STRATEGY NO. 7 -- ACTIVATED SLUDGE WITH AQUACULTURE LAGOON


STAGE I
PRIMARY TREATMENT
STAGE II
ACTIVATED SLUDGE WITH CHEMICAL ADDITION
STAGE III
AQUACULTURE RACEWAY
SURFACE WATER
SLUDGE HANDLING

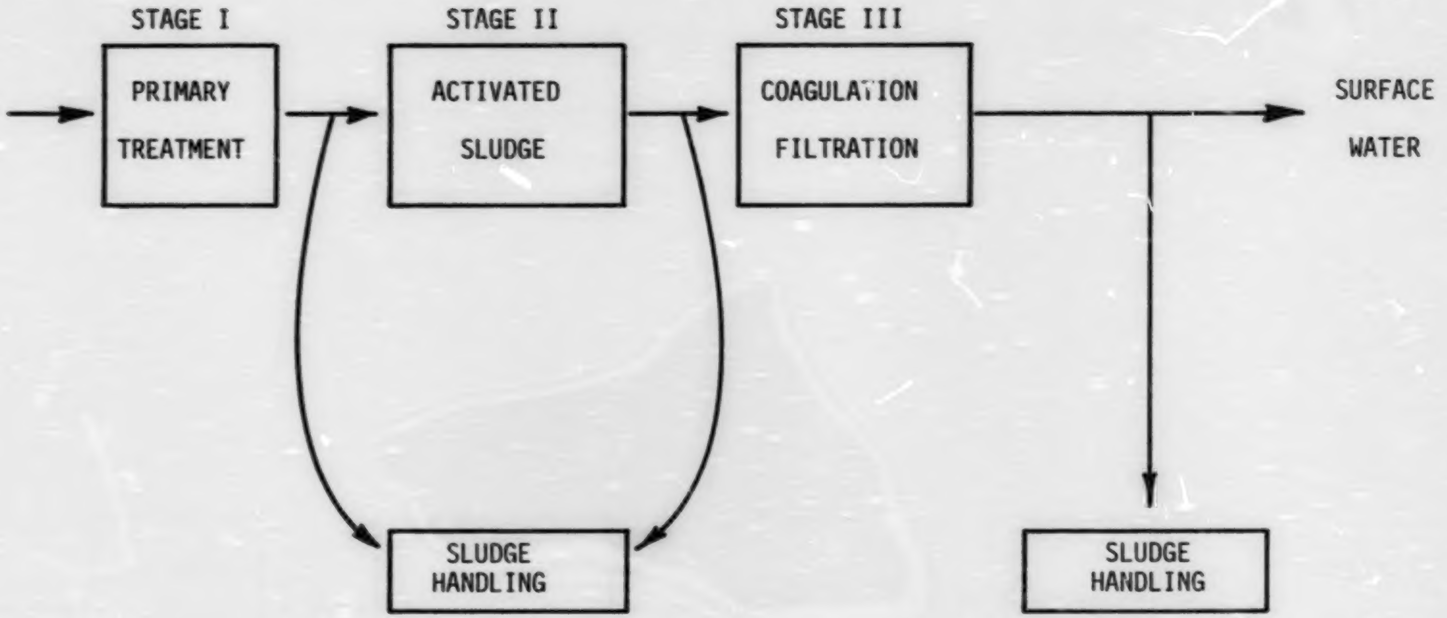
STRATEGY NO. 8 -- ACTIVATED SLUDGE, CHEMICAL ADDITION, WITH AQUACULTURE RACEWAY


STAGE I
PRIMARY TREATMENT
STAGE II
ACTIVATED SLUDGE WITH CHEMICAL ADDITION
STAGE III
AQUACULTURE LAGOON
SURFACE WATER
SLUDGE HANDLING

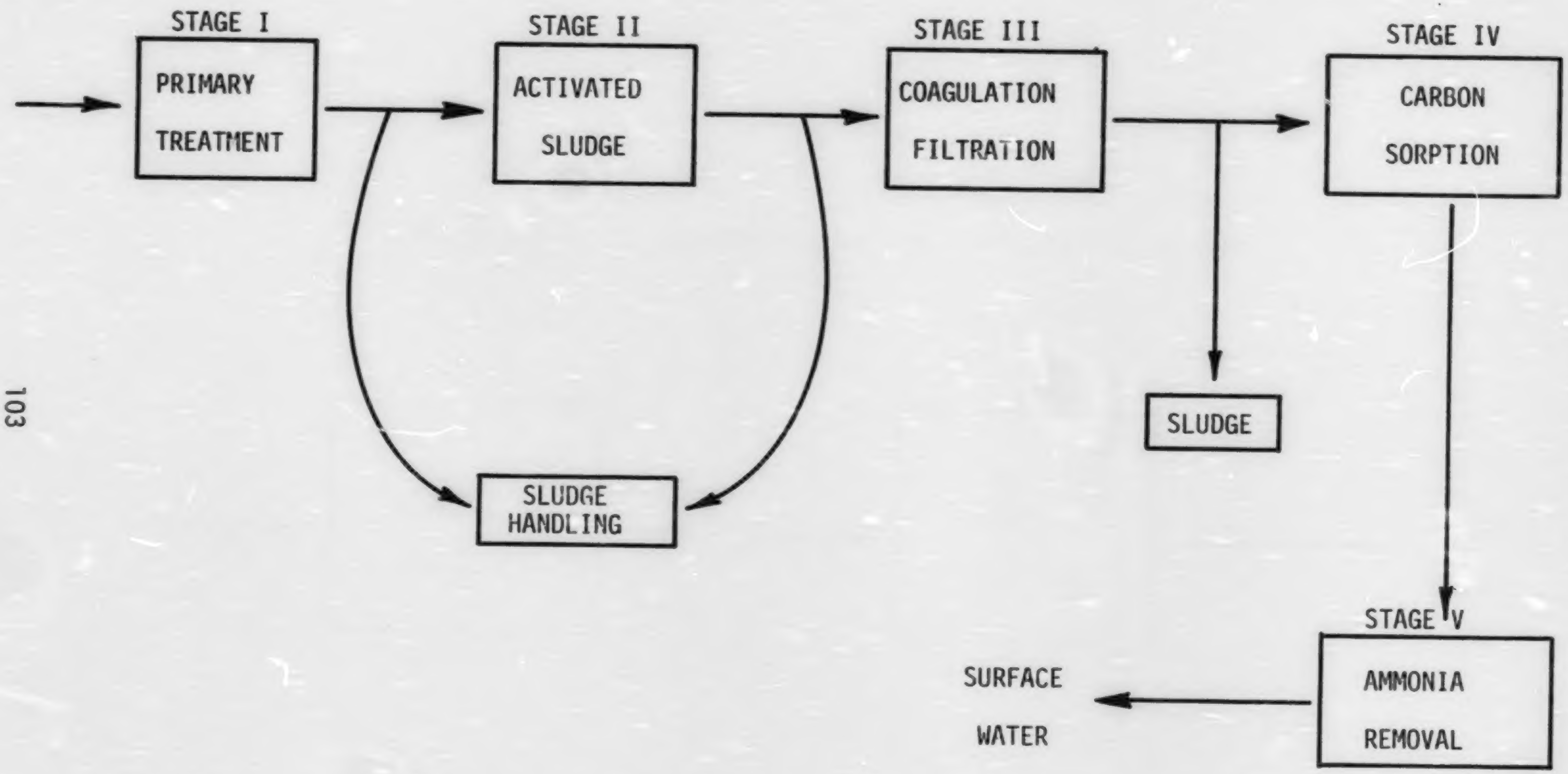
STRATEGY NO. 9 -- ACTIVATED SLUDGE, CHEMICAL ADDITION, WITH AQUACULTURE LAGOON


STAGE I
PRIMARY TREATMENT
STAGE II
ACTIVATED SLUDGE
STAGE III
NITRIFICATION
DENITRIFICATION
SURFACE WATER
SLUDGE HANDLING

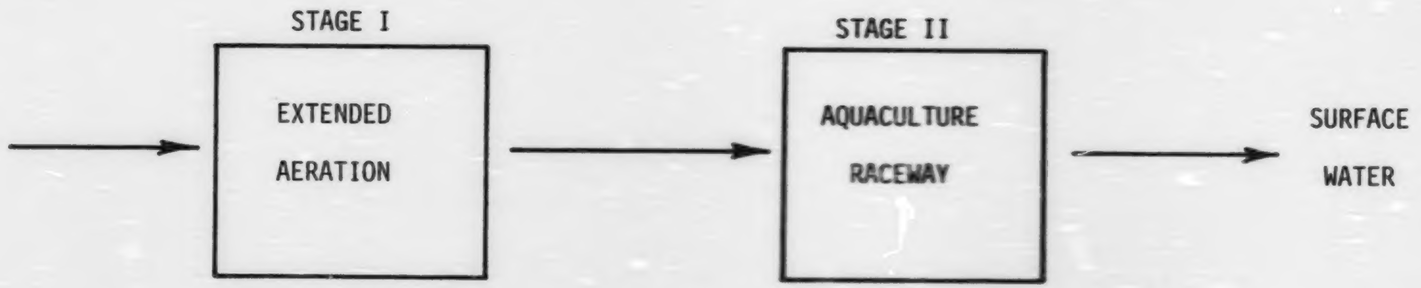
STRATEGY NO. 10 -- ACTIVATED SLUDGE, NITRIFICATION/DENITRIFICATION SYSTEM


STAGE I
PRIMARY TREATMENT
STAGE II
ACTIVATED SLUDGE
STAGE III
COAGULATION FILTRATION
SURFACE WATER
SLUDGE HANDLING
SLUDGE HANDLING

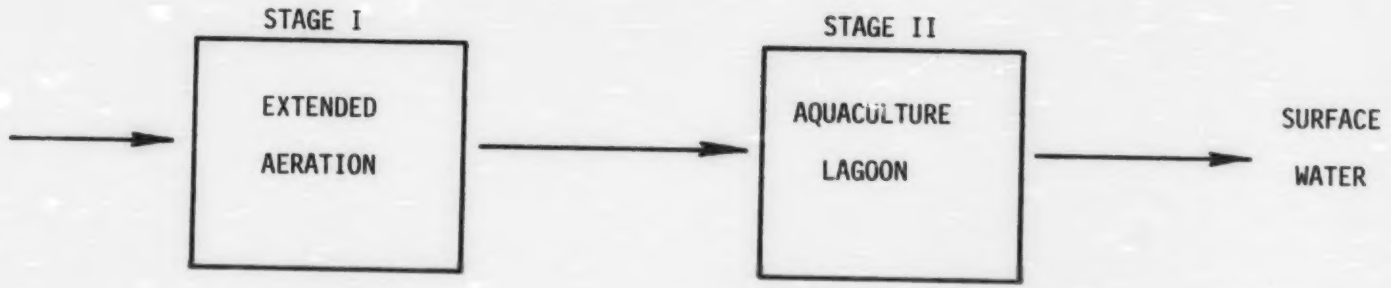
STRATEGY NO. 11 -- ACTIVATED SLUDGE WITH COAGULATION FILTRATION SYSTEM


STAGE I
PRIMARY
TREATMENT
STAGE II
ACTIVATED
SLUDGE
STAGE III
COAGULATION
FILTRATION
STAGE IV
CARBON
SORPTION
SLUDGE
HANDLING
SLUDGE
STAGE V
AMMONIA
REMOVAL
SURFACE
WATER

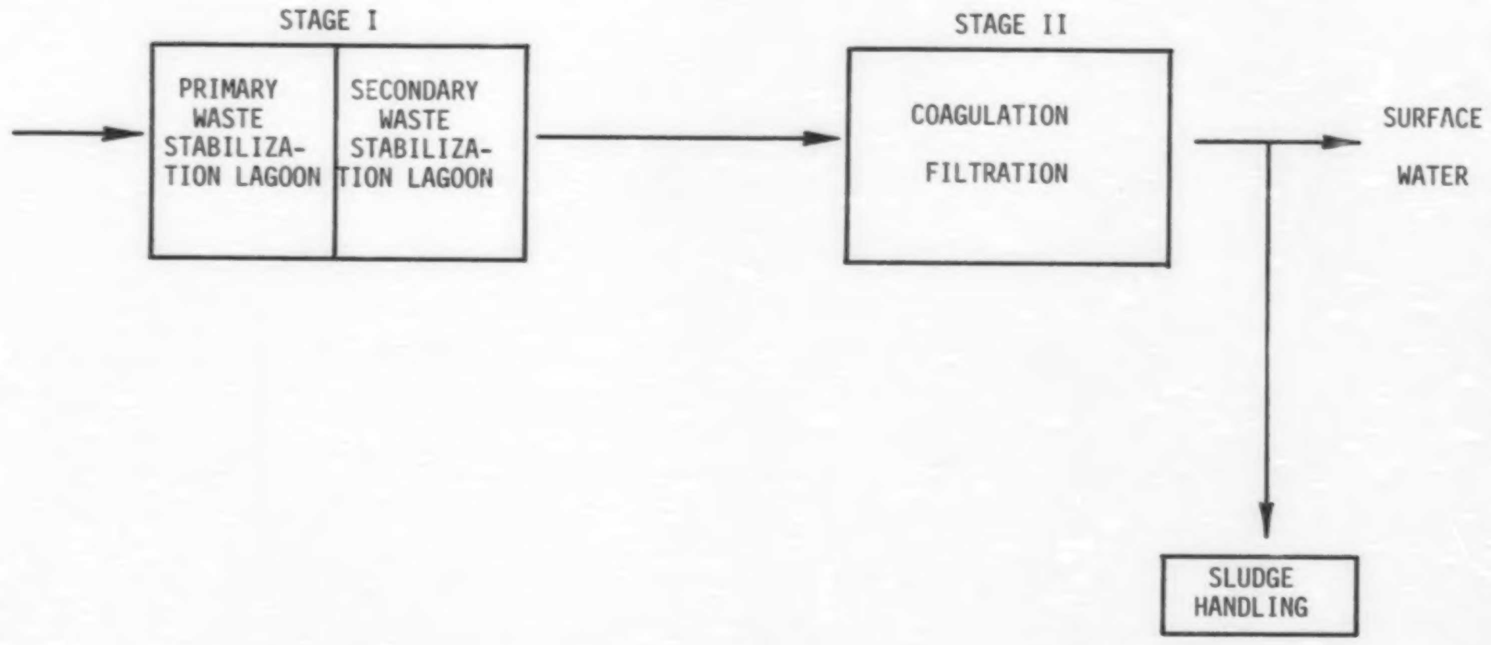
STRATEGY NO. 12 -- ACTIVATED SLUDGE - CARBON SORPTION - AMMONIA REMOVAL SYSTEM


STAGE I
EXTENDED
AERATION
STAGE II
AQUACULTURE
RACEWAY
SURFACE
WATER

STRATEGY NO. 13 -- EXTENDED AERATION WITH AQUACULTURE RACEWAY


STAGE I
EXTENDED
AERATION
STAGE II
AQUACULTURE
LAGOON
SURFACE
WATER

STRATEGY NO. 14 -- EXTENDED AERATION WITH AQUACULTURE LAGOON


STAGE I
PRIMARY WASTE STABILIZATION LAGOON
SECONDARY WASTE STABILIZATION LAGOON
STAGE II
COAGULATION
FILTRATION
SURFACE WATER
SLUDGE HANDLING

STRATEGY NO. 15 -- WASTE STABILIZATION LAGOON WITH COAGULATION FILTRATION